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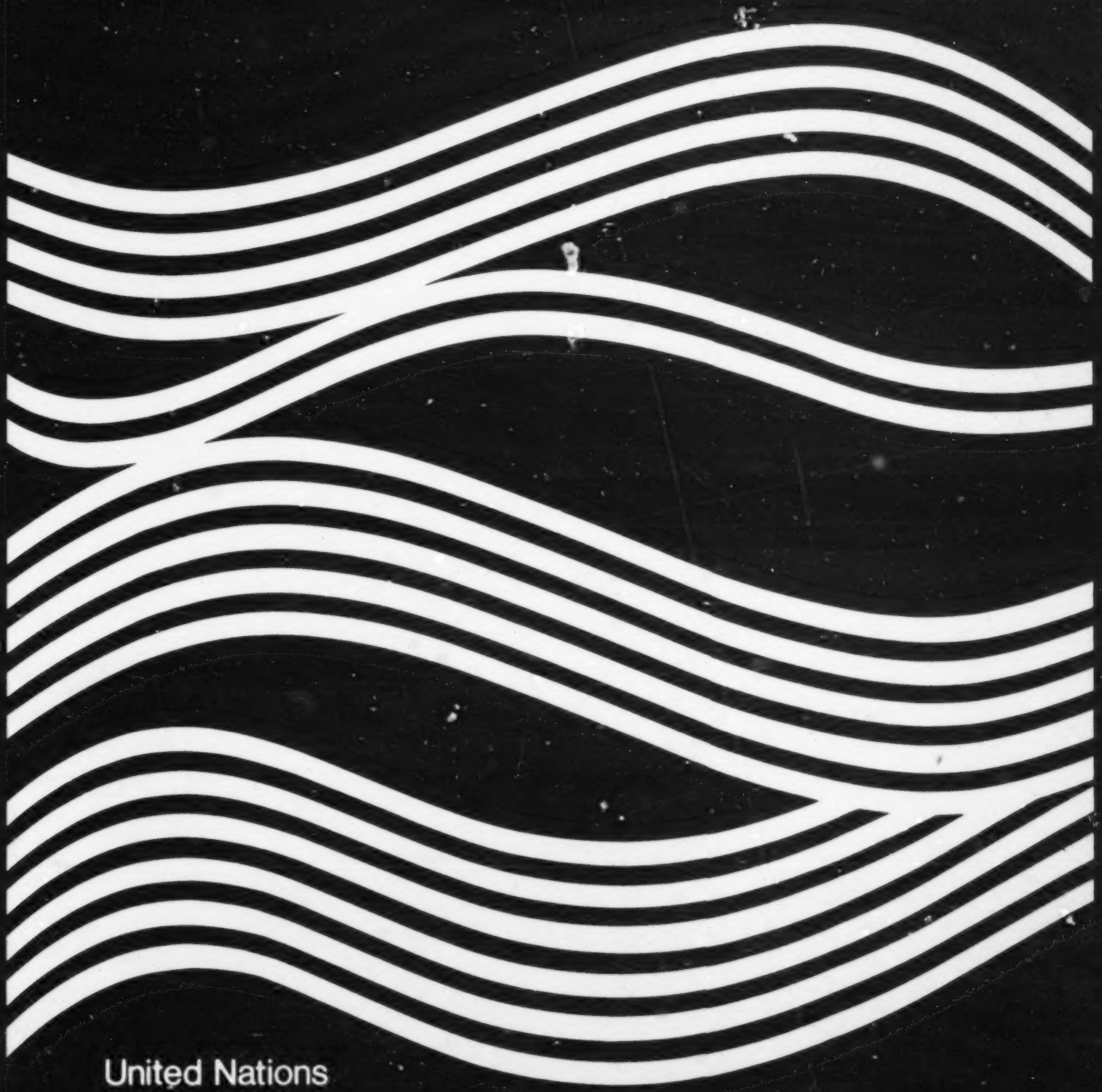

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Contents

	Page
Some propositions about irrigation projects and system management	1
Underground reservoirs to control the water cycle	6
A review of rainfall relationships based upon Indian data	16
The value of a long-range weather forecast for the West African Sahel	26
Flood studies led to national flood insurance	36
Research and development	41
Selective information section	43

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SOME PROPOSITIONS ABOUT IRRIGATION PROJECTS AND SYSTEM MANAGEMENT*

Introduction: The need for guidelines

The object of the present paper is to put forward some generalized propositions about certain aspects of irrigation management in developing countries on which, whatever the characteristics of a particular project or system may be, strategic decisions will at some point have to be made. The immediate purpose of the propositions is that they should stimulate debate (about their validity, the usefulness of this kind of generalization, etc.). But a longer-term objective would be to use them, after further testing against practical experience, as a basis for generating guidelines to decision makers for choosing the combination of institutions, management methods and, where possible, technologies most likely to be appropriate in a particular situation. The propositions are concerned primarily with projects dependent on surface-water delivery systems.

The work of the Agricultural Administration Unit at the Overseas Development Institute (ODI) is based on the assumption that attempts to generalize, and to develop broad guidelines about institutional and administrative choice are essential. This is largely because of the very crude or perfunctory reasoning on which so many current recommendations or decisions concerning institutions for agricultural development appear to be based, particularly those intended to improve access to the rural poor. In the field of irrigation management, the two most common bases for choice seem to be historical precedent (adherence to a local "model" within a particular geopolitical region) and automatic cross-cultural transfer. It is extremely rare to find any attempt to justify institutional choices by reference to the specific agro-climatic and socio-economic characteristics of the area concerned. We would argue, therefore, that the sooner guidelines can be developed which take account of these factors, the better, however imperfect or over-simplified they may appear to be initially.

The propositions advanced here are derived primarily from observations made during field research in north-west India and from the desk review of case studies in other parts of the developing world. The first set of propositions is concerned with the broader aspects of project organization and management, the second with more detailed aspects of water delivery system design and operations. But there is clearly a large degree of interdependence between propositions in each set.

A. Project management and institutions

Alternative management structures and methods of control

(1) In very general terms, there should be a high degree of correlation, or of "appropriateness" and "fit", between the organizational form and management methods of an irrigation project (ranging from authoritarian/centralized to participatory/decentralized) and its basic physical, technical, social and economic characteristics.[1]

(2) In the early stages of an irrigation project, strong official control, both technical and administrative, is likely to be beneficial, but over time (with increases in farmer knowledge and income, better and more varied market opportunities) increasing benefits are likely to come from decentralization of decision making and more farmer participation.

(3) On settlement schemes, official staff have opportunities to exercise over-all control and discipline by various means unconnected with the water delivery system (e.g. land tenure, cropping patterns, single channel marketing), which may assist rapid initial progress; but unless provision is made for adaptation over time, particularly with regard to land tenure, institutional rigidity and economic stagnation are likely to result at a later stage.

(4) On irrigation schemes introduced into previously cultivated areas, the choice of methods for exercising control and discipline is likely to be smaller and the difficulties of encouraging good water management in the initial stages correspondingly greater: depending on circumstances, choices will have to be made among methods of water control which are:

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* By A.F. Bottrall, Agricultural Administration Unit, Overseas Development Institute, London. Reprinted from International Commission on Irrigation and Drainage (ICID) *Bulletin*, vol. 27, No. 2 (July 1978), pp. 68-72, with special permission. This is a modified version of a paper presented at the ODI Workshop on Choices in Irrigation Management, held from 27 September to 1 October 1976 at the University of Kent, Canterbury, United Kingdom.

1 The range of possible management approaches (with examples taken mainly from the desk review study) is indicated in the table. To those who find it helpful to think in terms of "types" of management approaches and "types" of local situation, certain probable correlations are likely to suggest themselves immediately. But to draw firmer conclusions about the extent to which a particular kind of management approach (A) is likely to fit well with a particular kind of locality (B), it would be necessary to assess in some detail the performances of a fairly large sample of widely contrasting projects.

(a) administrative (e.g. strict supervision and policing of water use, crop zoning); (b) economic (e.g. high water charges); or (c) technical (e.g. more control structures). The choice may, of course, involve a combination of these methods.

Universal ingredients of good management

(5) In all newly-irrigated areas, the introduction of a strong agricultural and water management extension programme is essential, either from the inception of the project or, preferably, on a pilot basis before irrigation water is provided at all on a large scale.

(6) On all irrigation projects and at all stages in their development, the activities of the engineering and agricultural staff should be co-ordinated by a superior officer or agency with direct administrative control over both; close co-ordination between irrigation and agriculture is also required at ministry level.

(7) Project staff will generally perform better under a management which works on "commercial" rather than "bureaucratic" principles (e.g. promotion on merit, not seniority; rewards for good performance, punishment or dismissal for bad performance).

Project scale[2]

(8) Despite certain potential economies of scale on larger projects (e.g. larger reservoirs which permit reduced fluctuation in water deliveries; better opportunities for maintaining an effective local research capacity), farmers tend to be more efficient in their use of each unit of water delivered on smaller projects than on larger ones within the same locality. They are also likely to be more co-operative in accepting decisions about allocations of scarce water. This is because it is easier for them to obtain accurate information about over-all water supply and demand within the project area, e.g. total water availability may often be checked first-hand; and inequitable water distribution, whether between individuals or groups, is more easily identifiable and social pressures against abuse are therefore likely to be stronger.

(9) In the initial years of large-scale projects, with water delivery systems of limited flexibility, water supplies tend to exceed an unpredictable demand by a particularly large amount, especially when the whole project comes on-stream within a very short space of time. This leads to major water losses and in some cases serious environmental damage. Wherever possible, therefore, large projects should be developed on a stage-by-stage basis.[3]

Communication and feedback

(10) To assist communication and feedback between official management and farmers on large-scale projects, staff should be organized on a decentralized "irrigation sector" basis, with each sector headed by a co-ordinated irrigation-drainage-agriculture team, rather than be directed through long, extended centralized chains of command operating in parallel.[4]

(11) Key people in any extensive irrigation system are the most junior-ranking staff who are supposed to form the immediate link between the official management and farmers (ditchtenders, village extension officer); if for any reason they do not or cannot work effectively (e.g. poor incentives; inadequate contact with or supervision by senior officials), the over-all performance of the project will be severely affected, whatever the technical skill of top-level management.

Farmer participation and irrigation groups

(12) Farmers will be more inclined to accept group responsibility for operation and maintenance tasks at watercourse level if they have previously had to contribute resources (especially labour) at the construction stage towards the installation of local infrastructure, irrigation and drainage channels, land levelling, etc., as, for example, in China and on small "indigenous" irrigation systems elsewhere.

(13) When the Government offers external technical support to farmer-irrigator groups which are already well established as a result of spontaneous local action, great care must be taken to ensure that, if certain traditional functions are taken away from the groups (e.g. repair and maintenance of diversion structures), they continue to be given sufficient responsibilities to encourage retention of their dynamism and identity; otherwise they will tend to become dependent on the Government in all respects, with the result that performance deteriorates and/or major increases in administrative cost occur.

(14) Although local groups are administratively convenient, they cannot easily be created where they have not existed before: just as they are a number of reasons which can be found to explain why groups have tended to develop in certain environments (e.g. hill-valley topography and/or relatively easy local control of water source; social cohesion; coincidence between size of local social unit and size of terminal irrigation unit; rice cultivation, often with field-to-field flood irrigation; perhaps also population density and settlement pattern), so there are equally good converse

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2 The advantages of smaller scale and greater divisibility suggested in propositions 8 and 9 could be brought out still more strongly by reference to well irrigation.

3 This should also allow a more effective development of agricultural and water management extension staff (especially where these are in short supply), by permitting greater concentration of effort on different areas in sequence and making it possible for earlier-developed units to be used as demonstration areas for later-developed ones. See also proposition 5.

4 It should be possible to develop more detailed hypotheses about optimum densities and locations of staff (in accordance with their skills and functions) in different conditions, both through further field study and through study of management theory derived from experience in other types of enterprise. The same applies to the size and functions of farmer-irrigator groups.

reasons why they have not developed elsewhere. In the latter areas, little advantage is likely to come from blanket government decrees that (formally constituted) irrigation groups or associations should be established; if groups are to take root at all in such environments, they may often need to be developed on a selective basis, after careful research has been done into the possible functions and felt needs round which (initially informal) group activity might, with sensitive external assistance, be gradually built up.

(15) Although in many of the societies in which they are found indigenous groups may not be particularly democratic or egalitarian, attempts to replace them by formalized would-be democratic institutions, e.g. co-operatives as developed in North America or Europe, are likely to produce the opposite effect from that intended: instead of encouraging greater equity, they will tend to reinforce the power base of the existing local elite, and often little else. This effect is likely to be still more pronounced if such institutions are introduced into societies which are markedly unequal and lacking in social cohesion. In this latter case, the first step towards achieving greater equity should be the introduction of stronger official control and more effective penalties against abuse rather than loosely supervised unrepresentative farmer bodies.

B. System design and operation

System design and capacity to manage

(16) At the project planning stage, much more attention should be paid than is usually the case to relating the design of the system (a) to the capacity of the irrigation staff and the farmers to operate and maintain it, and (b) to the capacity of the farmers and the agricultural extension staff to raise the level of agricultural production at a rate which will justify the capital and recurrent costs which the design entails.

Maintenance and finance

(17) A frequent reason for poor system maintenance is the inadequacy of finances to cover a project's recurrent costs. This is usually directly or indirectly linked with a policy of low water charges.

(18) Highly subsidized water charges are rarely justifiable, though apologists for them sometimes argue: (a) that when irrigation is first introduced to an area farmers are inhibited from taking water by charges of any significance; or (b) that smaller farmers cannot afford higher charges at any time. In fact low water rate policies are usually maintained as a result of pressure from large farmers, who could easily afford to pay higher rates but are usually a politically powerful pressure group.[5]

System operation

(19) The method of system operation (matching water supply and demand as closely as possible) and, by extension, the design of the system which has to be operated, should be chosen according to agro-climatic criteria, not geo-political ones.

(20) There appear to be a limited number of significantly different techniques for attempting to optimize the match between water supply and demand on surface-water delivery systems. According to its design (and cost) a system may offer more or fewer opportunities for flexibility of supply, depending on whether (a) it is with or without storage (b) it is designed to operate on a 24-hour basis, by rotation or on demand. On the demand side, water demand estimation and control of water use may be facilitated by legislative controls over cropping, whether by area or type; or choice of cropping pattern may be merely limited *de facto* by scarcity of water supply or the farmer may have free choice of cropping. On the basis of socio-economic and agro-climatic criteria (propositions 16 and 19) it should be possible to develop a rationale for choosing appropriate system designs and operating methods for particular localities.

(21) On most irrigation projects in which the combination of system design and cropping policy requires an efficient reporting service from the field to improve estimates of local seasonal water requirements and to facilitate subsequent modifications to the planned water delivery pattern, insufficient use is made by the engineers of agricultural staff as a source of information and assistance.

Operation and Maintenance at watercourse and farm levels

(22) Other things being equal, there is a positive correlation between (a) the scarcity of water supplied to the farmer and/or the cost to him of using it and (b) the efficiency with which he applies it and contributes to local operation and maintenance activities, provided that the supply pattern is (i) predictable and (ii) not so scarce as to damage crop growth severely.

(23) A precondition for the practice of rotational irrigation at the watercourse level is some degree of water scarcity in relation to demand, conversely, the provision of excess water (or the absence of administrative or physical controls over the acquisition of excess water) fosters "water anarchy".

(24) The formation of irrigation groups or associations is not a necessary condition for the introduction of rotational irrigation at watercourse level; in some cases it may be preferable for rotations to be established and, when necessary, supervised by official staff (cf. proposition 15).

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5 The reasons for slow up-take of water by farmers at the beginning of many irrigation projects may often have little to do with the level of irrigation charges, e.g. ignorance of irrigation practices; labour bottle-necks or shortage of draught power or machinery for land preparation. The capacity of smaller farmers to pay higher charges will obviously vary from situation to situation, but if the subsidy is intended as a welfare measure, this is an inefficient (and inequitable) way of providing it; where needed, separate welfare measures should be found.

Table

	⇐ *More centralized*						*Less centralized* ⇒
	MWEA (Kenya)	*Gezira (Sudan)*	*Medjerda (Tunisia)*	*Egypt*	*W. India (Maharashtra)*	*N.W. India (Chambal)*	*S.E. Asia (Traditional)*
A. Management Characteristics							
1. Main operating agency	Parastatal Board	Parastatal Board	Parastatal Board	Governement Departments	Government Departments or CAD Authority	CAD Authority	Farmer groups
2. Methods of official management control	(*a*) threat of tenant expulsion (b) control over crop rotation (c) control over timing of cultivation operations (*d*) control over water delivery to field (*e*) control over all marketing outlets (*f*) "social control" – policy of mixing clan groups	(*a*) threat of tenant expulsion (b) control over crop rotation (*c*) control over water delivery to 10-farm outlet (*d*) control over cotton marketing outlets	(*a*) sanctions against non-repayment of land purchase loan (*b*) partial control over cash crop marketing (*c*) control over water delivery to – (unspecified) level	(a) control over cropping pattern and rotation ("blocks") (*b*) control over water delivery to – (unspecified) level (*c*) control over all marketing outlets	(*a*) control over area and acreage of certain crops especially sugarcane (*b*) partial control over water delivery to farm by indent (*c*) control over water delivery to watercourse	(*a*) control over water delivery to watercourse outlet (*b*) legislation against damage, abuse (ineffective)	often none
3. Density of official staff coverage	1 irrigation officer: 3,000 acres, 1 junior extension officer and waterguard: 500 acres (120 farmers)	–	–	–	–	1 junior engineer: 18,000 acres, 1 village extension worker: 320 farmers	–
4. Farmers' responsibilities	Labour-intensive cultivation activities	All cultivation activities excluding land preparation; water application to field	All cultivation activities; water application to field	All cultivation activities excluding land preparation; water application to field; O and M (including rotation?) within watercourse	All cultivation activities; water application to field; informal participation in water allocation and maintenance within watercourse	All cultivation activities; water application to field; informal participation in water allocation and maintenance within watercourse	Cultivation conservation and O and M of whole system

B. Project Characteristics

(1) *Physical*							
Soils	Uniform back clay	Clays	Alluvial deposit: valley basin between sandstone cliffs	–	Clays, undulating	Clays, undulating	–
Rainfall (average)	Medium	Low	400-1,000 mm/yr to the north; 200-400 mm/yr to the south	75-200 mm/yr	High	630 mm/yr	High
(2) *Technical*							
Project irrigated area	12,000 acres	2,000,000 acres	–	–	–	550,000 acres	c. 100 acres
Type of system design	Division, gates to field	Storage: night storage	–	–	–	Storage: control structures to head of minors	Simple diversion
Date of construction	Late 1950s	Late 1920s	–	–	–	1960	–
Cropping pattern	1 Crop rice only	Cotton and subsistence	Livestock, horticulture	Cotton and subsistence	Sugarcane and subsistence	Wheat, rice, coarse grains	Mainly rice
Cropping intensity	100%	65%	–	? 200%	–	76%	–
Water scarcity/ abundance	No shortage at present	Sufficient	–	Watercourse rotation	–	Excessive at head, deficient at tail	? Abundant
(3) *Social/economic*							
Settlement/non-settlement project	Settlement	Settlement	Post-land reform settlement	Mainly smallholders (post-land reform)	Large and smallholders	Large and smallholders	Smallholders
Type of tenure	1 year renewable tenancy	1 year renewable tenancy	Purchase of land over 2 years	Mainly private ownership	Private ownership and tenancy	Private ownership and tenancy	Private
Average farm size	4 acres	15-20 acres	–	–	–	8.5 acres	–
Average farm income	(target income £ 100 p.a.)	–	–	–	–	–	–
Length of farmer experience of agriculture/irrigation	? 5-10 years	Originally nomadic pastoralists	Mostly previously landless	–	–	10-15 years	–
Literacy rate	–	–	–	–	–	16%	–

UNDERGROUND RESERVOIRS TO CONTROL THE WATER CYCLE*

One tends to think of the global water cycle as proceeding in the following way. Water is evaporated from the oceans by solar energy; meteorological processes transport it through the atmosphere, from which it falls to the earth as rain or snow, and eventually it returns to the oceans by way of rivers and streams. This picture overlooks the enormous amounts of water that reside for various periods of time (from weeks to millenniums) in underground reservoirs. Moreover, few of the people involved in planning the distribution of water resources have recognized the opportunity the underground reservoirs provide for dealing with the water shortages that increasingly beset agriculture and other human activities in various parts of the world and for greatly increasing the amount of water that could be put to the service of human endeavor. In this article I contend that mankind should deliberately draw down the underground reservoirs – far more than it already does to some extent – to meet the needs of agriculture, industry and community activities, because sooner or later nature, sometimes abetted by human efforts, will refill the reservoirs. The result will be a vastly increased control of the water cycle and an avoidance of the struggles over water that virtually every nation will face within the next few decades if the present wasteful practices in the management of water are continued.

The widespread crop shortages of 1972 provided an indication of the difficulties that lie ahead if water is not managed more efficiently. The shortages were the result of a deficit of some 400 cubic kilometres (400 billion cubic metres) in the continental part of the water cycle. On the global scale of water flow the deficit was small, but it had a heavy impact because most countries use water in such a way that they have little margin for dealing with the consequences of drought. Under present practices the production of food in the world is coming dangerously close to the limit of self-sufficiency. The prevention of food crises will in the future require the manipulation of water on a far larger scale than nations have practiced up to now. One can envision the need for a great increase in irrigation and for the transfer of water between river basins and even between continents.

People involved in the management of water draw a distinction between renewable water resources and non-renewable ones. The conventional water cycle I have described carries the renewable resources, which amount to about 500,000 cubic kilometres per year. The non-renewable resources have a volume of 1.5 billion cubic kilometres. They are stored in three reservoirs: the oceans (97.3 per cent of the resources), the continents (2.7 per cent) and the atmosphere (.0001 per cent).

These distinctions overlook the fact that all the water resources of a continent proceed through a cycle. The only difference between renewable and non-renewable resources is the speed with which the water is cycled. The resources that are called renewable move fairly rapidly, whereas the non-renewable resources move quite slowly.

The period of time a particular amount of water spends in its cycle is termed its residence time. Water in the atmospheric reservoir may have a residence time of 10 days. Deep in the oceans the residence time of a body of water may be more than 1,000 years. The residence time of continental water resources ranges from a few weeks to many milleniums, depending on the type of reservoir: a river channel, a lake, a swamp, a glacier, polar ice and ground water. The ground-water reservoirs show the largest diversity of residence time: a few days or weeks in karst (limestone) aquifers, a few weeks or months in gravelly riverbeds, a few months or years in alluvial deposits, a few years or decades in other unconfined aquifers and a few decades, centuries or millenniums in confined aquifers.

Let us look more closely at the movement of water in the conventional water cycle. The annual evaporation from the oceans and the continents is about 500,000 cubic kilometres per year: 430,000 from the oceans and 70,000 from the continents. The other part of the equation is precipitation, which averages 110,000 cubic kilometres per year over the continents and 390,000 cubic kilometres over the oceans. To put it another way, the oceans yield 430,000 cubic kilometres by evaporation and receive 390,000 in precipitation, whereas the continents lose 70,000 by evaporation and receive 110,000 in precipitation. Hence every year 40,000 cubic kilometres of fresh water is transferred from the oceans to the continents. In accordance with the principle of the conservation of water within the water cycle, every year 40,000 cubic kilometres returns to the ocean in the form of surface and underground runoff.

One might therefore suppose 40,000 cubic kilometres of water per year would be available to mankind if water resources were managed with the utmost effi-

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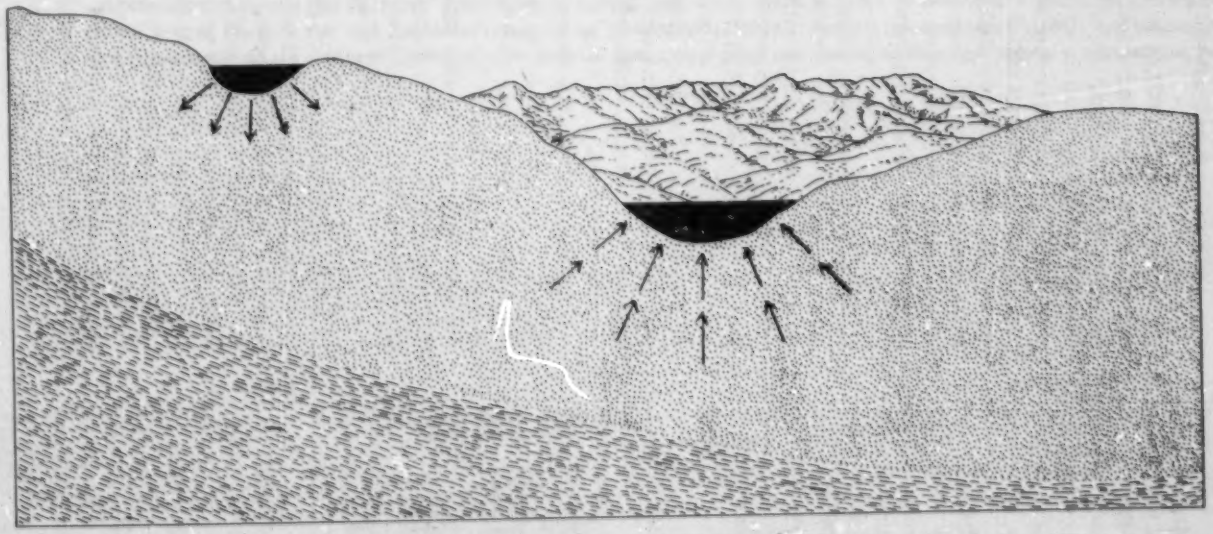
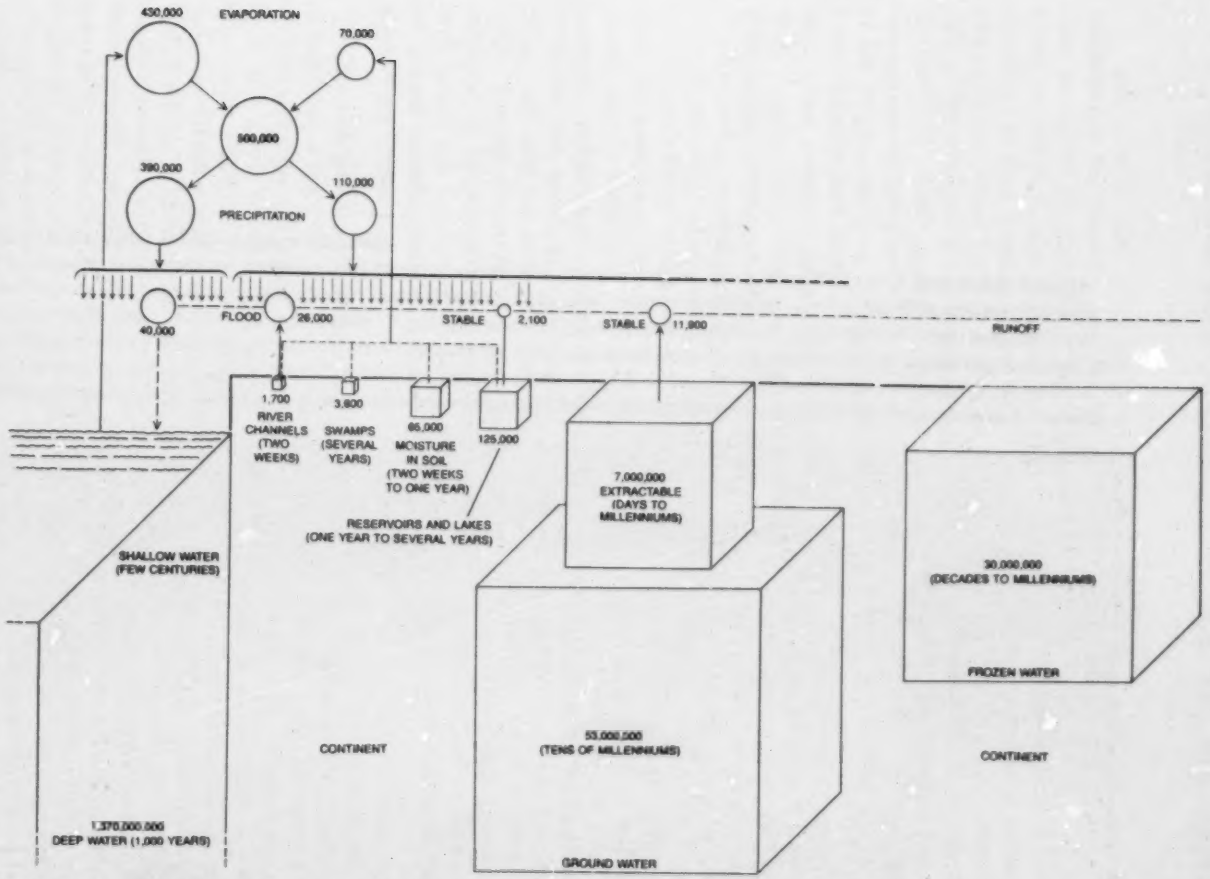


Natural underground reservoir is filled when water percolates into permeable soil or rock formations under a river or stream, as in the example at the left. There it may remain for periods ranging from weeks to milleniums before it finds its way back into the global cycle of evaporation, precipitation and runoff. Ground water also constitutes a significant part of the flow of most streams, as is indicated by the lower river in this illustration. Other natural processes that contribute to underground reservoirs include rain and snow falling on the ground and seepage from lakes and swamps. Reservoirs depleted by intensive use can be refilled artificially by seepage from canals and man-made lakes and by the pumping of water into the ground in periods when the water supply exceeds demand.



Water resources of the world are depicted in a diagram that shows both the annual water cycle, which is represented in the upper part of the diagram, and the water stored in the oceans (bottom left) and on the continents (right). All numerals represent cubic kilometers of water. The period of time during which water is likely to remain in a particular storage area is also shown. Following the water cycle, one sees that 430,000 cubic kilometers of water is evaporated from the oceans and 70,000 from the continents, whereas precipitation is 390,000 cubic kilometers per year over the oceans and 110,000 over the continents. There is thus a transfer of 40,000 cubic kilometers of fresh water per year from oceans to continents, which is balanced in the yearly cycle by runoff. All continental storage areas contribute to runoff, as is shown by numerals next to circles. Runoff from polar ice is omitted.

ciency. Actually much of that water is inaccessible; it consists of floods, water held in the soil, water running in uninhabited places and so on. The most that mankind might hope to utilize is about 14,000 cubic kilometres, which is the base, or stable, flow in rivers and streams. The base flow is regulated mainly by discharges from underground reservoirs (11,000 cubic kilometres), from man-made reservoirs (1,840) and from lakes (260).

Even the total of 14,000 cubic kilometres is not fully within reach unless transfers of water are made on an enormous scale, since a large part of the total is in uninhabitable areas. As of 1972 the amount of water under human control was approximately 3,000 cubic kilometres per year. Taking into account the fact that about 5,000 cubic kilometres of the stable river runoff is in inhospitable regions, there remains some 6,000 cubic kilometres that, under conditions of sound management, man could employ for his needs in the future.

The human species normally inhabit only 60 million square kilometres of the continents, being effectively excluded from such places as deserts, polar regions, high mountains and forests. Within the inhabitable zones about 3,200 million hectares of land are potentially usable for agriculture; in 1970 about 1,400 million hectares were under cultivation. It is unreasonable to suppose the amount of additional land that could be brought under cultivation over the next century would be as much as 1,000 million hectares. A better strategy in meeting the rising requirement for food would be to use land more intensively, with irrigation playing a major role. The amount of land under irrigation in 1970 was 180 million hectares. Irrigation consumed some 2,400 cubic kilometres of water per year. Industry consumed 500 and other human activities 200, so that mankind's worldwide consumption of water was 3,100 cubic kilometres.

The food crisis of 1972 arose from a deficit of 35 million metric tons of cereals (wheat, rice and coarse grains). A further consequence was that the wheat stocks of the exporting countries dropped from 50 million metric tons in 1971 to 30 million in 1974. Another year or two of deficit in rainfall would create a global food crisis with dramatic international implications. Thus it appears that the food situation in the world has reached a point where the effects of water deficiency are much more severe and more widely felt than they were in the past.

Another disturbing problem for food production is the possibility that the world's weather patterns may be changing. An example is offered by the northern circumpolar vortex, the great cap of high-altitude winds revolving around the pole from west to east. In recent years the lower edge of the northern vortex has been farther south than it was for some years previously. As a result the high-pressure zones have also been farther south, thereby blocking the monsoon rains out of the regions where they are vital to the survival of hundreds of millions of people. The rains therefore have fallen into the oceans or onto land areas that already have more than enough rain.

All these events raise the question of whether man is technologically capable of manipulating the water cycle in such a way as to prevent the calamities that might arise with prolonged shortages of rainfall or changes of climate. Certainly a fair number of technological efforts to deal with such problems have been made or proposed. They include cloud seeding, the long-distance transport of icebergs, the desalination of sea water and the storage of river floodwaters through systems of dams and reservoirs. How effective are these approaches?

The effort to induce precipitation by seeding with silver iodide, frozen carbon dioxide and other substances has not yet been put on a firm scientific basis. It remains a somewhat expensive and haphazard endeavor. Only a few of the many experiments in this field have demonstrated that cloud seeding can increase precipitation in a limited range of favourable conditions. Some experiments have resulted in less precipitation. In sum, weather modification is still in the research stage.

The towing of polar icebergs, mainly from the Antarctic, to arid continental coasts has been proposed. For example, it would be possible to tow a large iceberg (containing six cubic kilometres of fresh water) from Antarctica to the Atacama Desert in Chile in about seven months, with a water loss of 30 per cent. The iceberg would be moored at its destination and then melted or quarried for various purposes. Although nothing has actually been done along this line, it would be worthwhile to consider a pilot project for developing countries such as Chile and Peru. The Antarctic runoff amounts to about 2,000 cubic kilometres of icebergs per year, so that the water resource is considerable.

The desalination of seawater has attracted a good deal of attention, particularly because over the past decade the cost has been reduced from about $US 1.50 to about $0.50 per 1,000 gallons ($0.13 per cubic metre). The present trend is to build nuclear plants with the dual purpose of generating electricity and desalinating substantial quantities of sea water. This approach, however, appears feasible only for the domestic water supply of coastal regions in the affluent countries, in view of the capital investment required and the high cost of operating the plants. The present production of fresh water by this means is a mere three cubic kilometres per year.

Up to now the most effective method mankind has employed to manipulate the water cycle has been to build dams and reservoirs that control the flood cycles of rivers. Some 1,840 cubic kilometres of fresh water is stored in this way: 560 in Asia, 490 in North America, 400 in Africa, 200 in Europe, 160 in South

America and 30 in Australia. The prospects for a large expansion of the technology appear to be limited, however, particularly in the developing countries, because the cost of regulating one cubic kilometre of water per year by the dam-reservoir method now amounts to about $100 million. Moreover, the residence time of the stored water rarely exceeds a year, so that the system offers inadequate protection against a rainfall deficit that continues for more than a year.

Nevertheless, by building dam-reservoir systems mankind has unwittingly set in motion the long-term control of the water cycle through ground-water reservoirs. For example, the vast irrigation system of the Indus River basin in Pakistan, which was initiated in 1960, gave rise to a dense network of irrigation canals. A large proportion of the surface water diverted from rivers into these canals seeped into the underground reservoirs. The result was that the water table rose steadily for more than a century, creating a huge underground storage. Another example is afforded by the Aswan Dam in Egypt: several cubic kilometres per year are leaking from the reservoir behind the dam into the sandstone aquifer of the Western Desert of Egypt, the largest ground-water reservoir of the Sahara. Ventures of this kind suggest a long-term control of the water cycle through the artificial recharge of underground reservoirs. Is this a sound strategy for the future?

Nature annually cycles about 12,000 cubic kilometres of water through underground reservoirs to form the stable river runoff, or low river flow; this represents 30 per cent of the total runoff. Mankind meanwhile is regulating less than 2,000 cubic kilometres by dam-reservoir systems. On the other hand, only 1,200 cubic kilometres of the 3,100 cubic kilometres of water that mankind uses yearly comes from ground-water reservoirs. For more than a century governments have relied on the dam-reservoir approach and have largely ignored the resources available underground. Apparently the reason was that little was known about the condition and behavior of the underground water.

Underground reservoirs have various functions, including the supply, storage, mixing and conveying of water. Until now mankind's main reliance has been on the supply function, that is, on drilling wells that tap the underground supplies. Only in California and more recently in Israel has much attention been given to the storage function. California diverts a good deal of water from the north, where it is abundant, to the south, where it is scarce. Ground water has been extensively depleted by pumping in the south, and much of the water transferred from the north serves to replenish those ground-water reservoirs. The depleted reservoirs therefore provide a mechanism of storage.

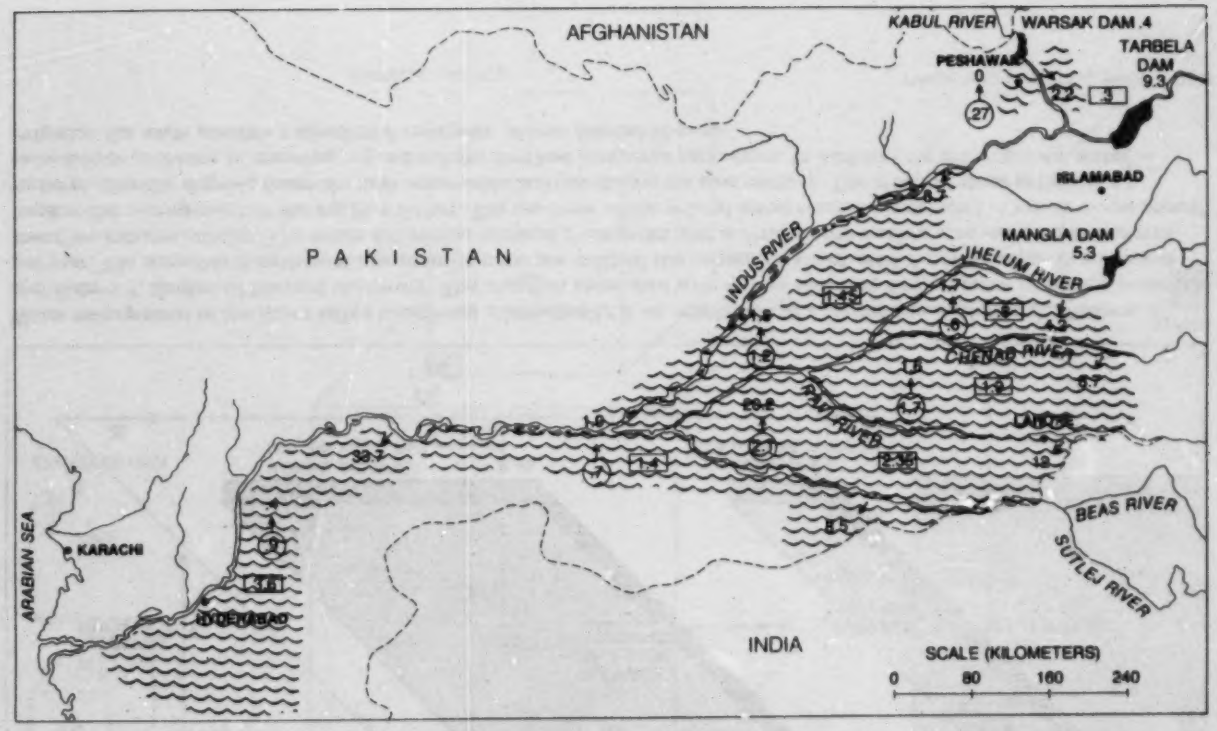
Similarly, in Israel the National Water Carrier System transfers 300 million cubic metres of water per year from the north to the south. Some 200 million cubic metres of it is stored in winter in the two main ground-water reservoirs of sandstone and limestone. The objectives are to cover the peak demand for water in the summer and the higher demand in years of low rainfall and also to improve the quality of the water through mixing.

Obviously a ground-water reservoir that is full cannot be employed for additional long-term storage. This was the condition of almost all the world's ground-water reservoirs until the 19th century, when the technology of drilling and pumping became widespread. Nevertheless, even now only a few ground-water reservoirs are depleted enough to provide space for trapping water from the water cycle. Part of the problem is that hydrologists are generally conservative and insist that the exploitation of ground-water reservoirs be kept below the "safe yield", which is defined as the amount of yield that can be expected to be replaced by natural recharge during the year.

Any reservoir managed in this way must be considered a saturated reservoir. It has no room for deliberate recharging for long-term storage, which is the best way to control the water cycle. The first condition for long-term storage therefore is to deliberately increase the exploitation of an aquifer beyond the safe yield. If it is possible, the exploitation should also carry the level of the reservoir below its natural outlets. In short, the policy should be to overexploit the reservoir.

Such a policy implies attention to the problem of recharging the reservoir, which can be done either naturally or artificially. The natural recharge of a ground-water reservoir results from the downward percolation of water from streams and also of water that falls as rain or snow on permeable soils. Experience over the past three decades has shown that a single year of unusually heavy rainfall, which can be expected at least once in 15 years, will replenish an aquifer that has been drawn down from 10 to 20 metres during previous years. For instance, the floods of 1969 in Tunisia replenished all the reservoirs that up to then had been described as overexploited. Similarly, a shallow aquifer in the Souss Valley of Morocco had supported a flourishing production of citrus fruit since 1946 but by 1957 was a source of great concern because the water table had declined at a rate of one metre per year. The rains of 1957 were well above normal; they recharged the aquifer by about 10 metres, almost restoring the initial situation.

Nature is therefore already operating a long-term storage system with some 10 or 15 years of residence time, which represents the best security against droughts or years of low rainfall. It is probable that further experience with ground-water reservoirs will reveal that in some places it may be possible to deplete a reservoir for as long as 40 years and still have it refilled by natural processes. Indeed, we already know that a much longer storage time (centuries of millenniums) was arrived at

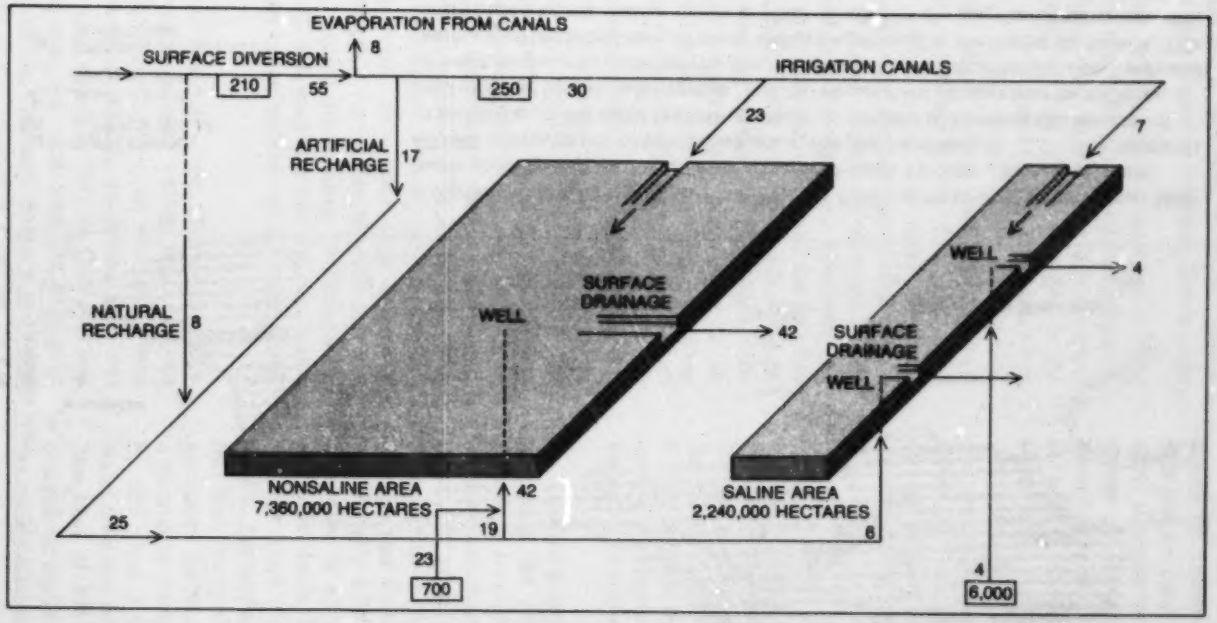


SUPPLY FROM SURFACE WATER (6.3)

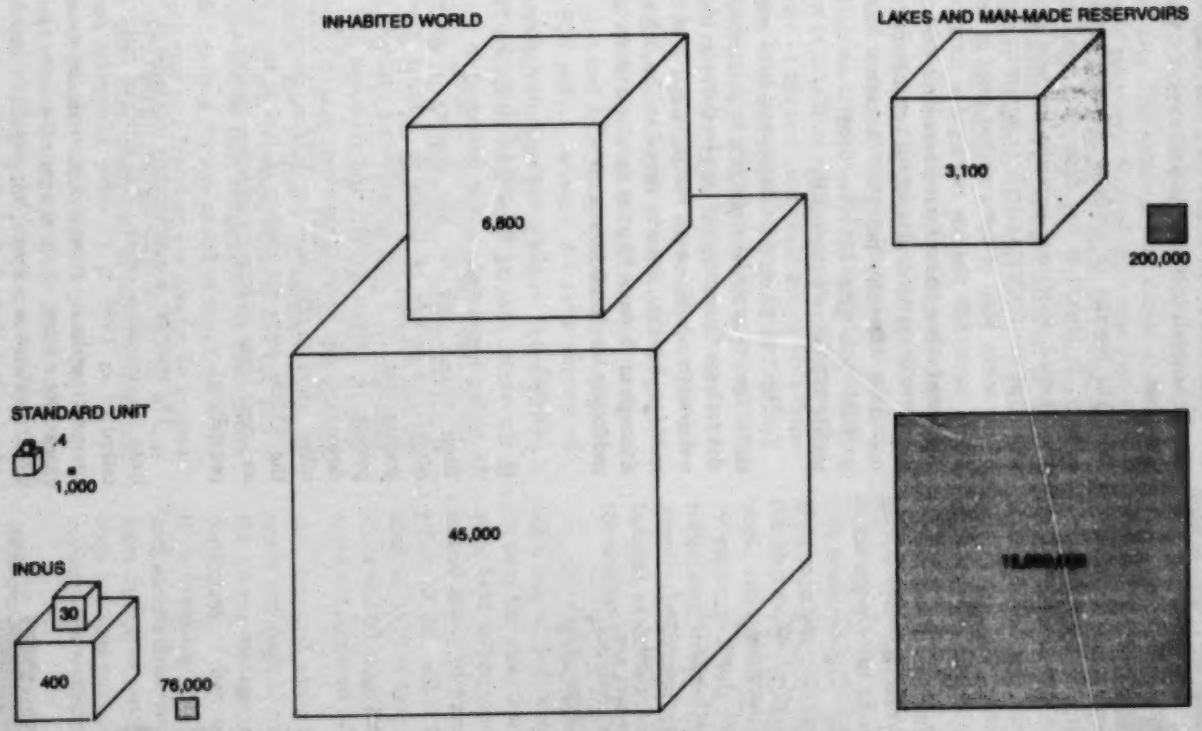
SUPPLY FROM GROUND WATER

STORAGE IN RESERVOIR BEHIND DAM

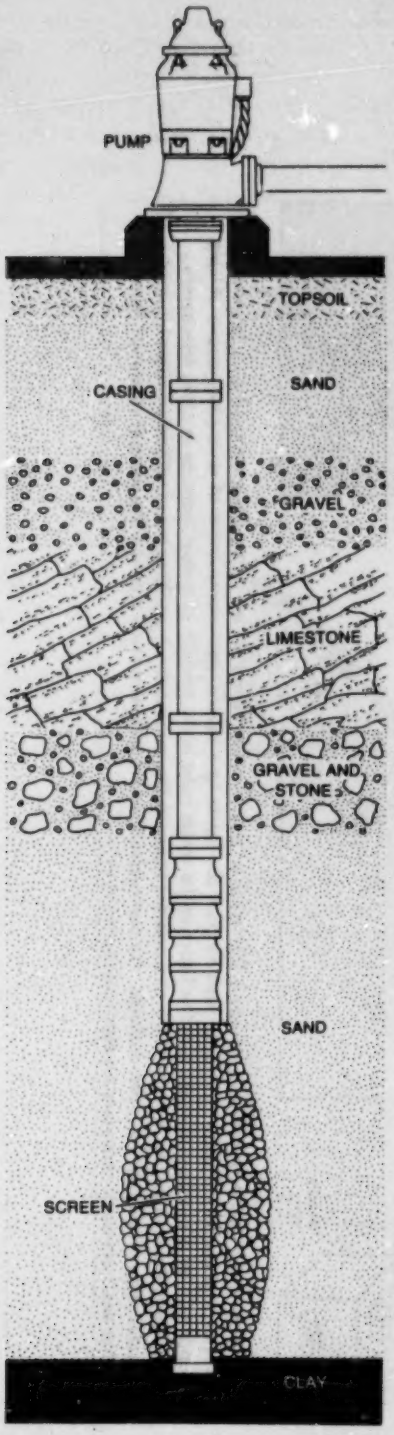
Irrigation system of the Indus River basin in Pakistan represents an enormous man-made contribution to the reservoir of ground water through a system of some 60,000 kilometers of canals, which are in the regions shown in ≈. The numerals in rectangles in the canal regions represent in millions of hectares the amount of land affected by the canal system, and the numerals in circles show in millions of hectares the area underlain by ground water of usable quality. All other numerals represent cubic kilometers of water and are explained in the legend at the left. The construction of the system began in 1860. Gradually the seepage of water into the ground from canals raised the water table so high that it began to interfere with agriculture. Now system is managed so as to deliberately pump some ground water out for use in irrigation.



Water management in the Indus valley is depicted schematically in an adaptation of a conception of Harold A. Thomas, Jr., and Robert P. Burden of Harvard University. The numerals associated with arrows show the flow of water in cubic kilometers per year. The numerals in rectangles represent (in parts per million) the concentration of total dissolved solids in water and therefore indicate salinity. The entire 9.6 million hectares of irrigated land is divided into a saline area and a nonsaline area because the management of the aquifers differs. The top layer of the ground-water reservoir is pumped in excess of the annual recharge, thereby drawing down the high water table built up during the past century. The effect of these actions is a reduction in problems of waterlogging and salinity that had hampered agriculture. In addition the use of ground water in irrigation has made possible a substantial expansion of area planted to crops.



Storage and recharge of water in the upper 30 meters of ground-water reservoirs are shown for a standard unit, for the Indus region and for the inhabited world. In each diagram the figure by a square represents number of square kilometers of land underlain by ground-water reservoirs; the figure in the upper cube is the amount of annual recharge in cubic kilometers, including the artificial recharge in the Indus, and the figure in the lower cube shows how many additional cubic kilometers of usable and recoverable water are available. For comparison the amount of surface area and the amount of annual recharge in lakes and man-made reservoirs are also shown.



Cased well, which in the Indus region is called a tube well, is portrayed. Such wells are the means whereby ground water is drawn down in the Indus valley as a source of irrigation and also of management of the ground-water resources. The well is made by drilling to a depth of from 30 to 70 meters and putting into the hole a casing ending in a screen that is some distance into the water table. Screen keeps out the large particles of solid matter.

by nature in the huge ground-water reservoirs that exist under deserts such as the Sahara. Recent studies have shown that the recoverable water from those reservoirs would make possible the irrigation of several hundred thousand hectares of land for centuries, even if it were assumed that the natural recharge of the reservoirs was insignificant. Mankind's perpetual quest for more water means, however, that close attention should be given to the artificial recharge of underground reservoirs.

The practice of artificial recharge began in this century. In general it was done on a small scale and with limited objectives: restoring the level of a water table that was declining rapidly or improving the quality of the water. Most of the work was done in California, where some 300 stations recharged a total of about eight cubic kilometres of water between 1900 and 1960. Since 1960 the level of artificial recharge has reached one cubic kilometre per year. A certain amount of artificial recharging has also been done in Europe, mainly to improve water quality.

The later plans of California and Israel mentioned earlier involve artificial recharging on a larger scale and also embrace the concept of long-term storage in ground-water reservoirs. The most striking example of artificial recharge, however, is to be found in the Indus valley, although until about 15 years ago it was an uncontrolled and largely incidental process.

The Indus project is the largest irrigation system in the world, covering more than 10 million hectares. As earlier mentioned, it was developed in the Indus River system over the past century. A network of 60,000 kilometres of canals in Pakistan covers the greater part of a vast ground-water reservoir encompassing 16 million hectares and extending 350 metres downward. The reservoir has a bottom layer of relatively saline water (6,000 parts per million, compared with the 35,000 parts per million in typical seawater) and an upper layer with water of higher quality (700 parts per million).

The reservoir is continuously recharged by leakage from the irrigation canals. This artificial recharge was estimated in 1969 at 17 cubic kilometres per year, compared with eight cubic kilometres of natural recharge. As a result of these inputs the water table rose by 30 centimetres per year, bringing about waterlogging in many parts of the Indus valley and causing problems of salinity in the soil.

A group from Harvard University studied this situation as part of a project sponsored by the World Bank. The team proposed making use of the ground water for irrigation and water management. Part of the plan was to mine the ground water for 30 years to lower the water table and alleviate the salinity problem. The water thus pumped must be diluted by canal water in order to keep an acceptable level of salinity near the

roots of irrigated plants. In addition the water taken out of the ground-water reservoir must be carried off to the sea through the canals.

The water the Indus system has trapped from the water cycle over the past century and stored in underground reservoirs represents today a volume of about 400 cubic kilometres of usable water stored in the upper 30 metres of the part of the aquifer that is overlain by the irrigated area. The water has been mined by means of a system of tube wells. Most of them were drilled by private enterprise to a depth of about 30 metres; they draw water up at the rate of about 30 litres per second. Tube wells installed by government agencies go to a depth of about 70 metres and discharge at a rate of about 120 litres per second.

The result of these activities is that ground water, heavily supplemented by artificial recharge, is contributing a third of the water supply in the region and has made possible an expansion of four million hectares in the amount of land from which crops can be harvested. Each hectare of irrigated land could also benefit from 40,000 cubic metres of usable water stored underground over the past century. The exploitation of this stored water could allow either an annual extension of the cropped area or a guarantee of full irrigation in times of severe drought or several years of low rainfall. At present prices one cubic kilometre of usable water per year could be produced from the ground-water reservoir for about $US 20 million, whereas the same amount of water trapped from the water cycle with a dam and reservoir would cost $US 100 million.

Such a system is the key to the future of agriculture and of water management if food production is to keep pace with the increase in population and the availability of water is to keep pace with the rising demands being put on water resources. The joint operation of surface and underground reservoirs will alleviate both seasonal and long-term deficiencies of water. The success of such a system requires that the underground reservoirs be fully equipped for an exploitation that could continue for any period of time from a few months per year to a few years per decade. To prepare such a system calls for political decisions that up to now have not even been considered in most jurisdictions.

The application of systematic management to aquifers is only in the exploratory stage. Further experience could improve the techniques employed in the management of water resources in general and of ground-water reservoirs in particular.

A case in point is the technology of artificially recharging ground-water reservoirs on a large scale. If that technology were improved, the ground-water reservoirs would serve for both seasonal and prolonged storage. Moreover, the total supply of manageable water would be increased because the system would save water that otherwise would evaporate or escape unused.

Seepage from irrigation canals is one of the best techniques for artificially recharging ground-water reservoirs on a large scale. Accordingly the lining of canals, which is often done to reduce seepage, is in fact a useless expenditure. It would be better to remodel the canals and enlarge them, provided that the work were closely co-ordinated with the installation of tube wells to control the rising of the water table.

Another means of artificially recharging ground-water reservoirs in temperate zones is to spread the high waters from winter thaws over bare irrigable land, that is, to irrigate the land even though no crops are growing. The technique would provide both a temporary storage in the soil that would be useful to the crops when they were planted and a long-term storage in the ground-water reservoir underlying the irrigated area.

A simple and very old technique for recharging ground-water reservoirs is to build lakes and small dams in the upper basins of rivers, so that some of the water that would normally run off will seep into the ground. More expensive techniques are to build infiltration pits (an excavation to catch storm runoff that otherwise would run uselessly out to sea) and recharging wells, by means of which water is pumped into the ground rather than drawn from it. In the United States of America, infiltration pits and recharging wells have been installed extensively on Long Island, in Arkansas, on the northern Great Plains and in certain Western states.

On a global scale the problem facing manking is not a lack of fresh water but a lack of efficient regimes for using the water that is available. The need to produce more food will continue, and it can be met only by an assured supply of water in agricultural areas. The water deficit of 400 cubic kilometres that caused the food crisis of 1972 is insignificant when one considers that about 45,000 cubic kilometres of water is still in storage in the top 30 metres of ground-water reservoirs.

Mankind can solve the water problem if governments and decision makers are prepared to embark on the proper management of their water resources and particularly of their reserves of ground water. Moreover, it is becoming technologically feasible to deal with such adverse developments as water deficiencies resulting from changes in weather patterns by initiating the large-scale and long-term control of the water cycle through ground-water reservoirs.

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A REVIEW OF RAINFALL RELATIONSHIPS BASED UPON INDIAN DATA*

1. Introduction

The need for development of water resources has assumed considerable importance in recent years, owing to rapid growth in population and tremendous expansion in industry and agriculture. In the absence of long-term hydrological data, planning and design of water resources projects have to be based upon past data of rainfall and other meteorological parameters which are available over a long period of years.

In recent years comprehensive studies on rainfall distribution in India have been carried out in the Indian Institute of Tropical Meteorology (Poona) with a view that these studies may be useful to design engineers and hydrologists who are engaged in the development of water resources projects. The results of these studies have been published in various scientific journals and research reports. An attempt has been made in this article to summarize briefly the results of some of the important studies so that field engineers of India and other countries of the region who do not have easy access to scientific and technical journals can benefit from these studies.

2. Rainfall of India and its subdivisions

The entire raingauge network of the country at present comprises about five thousand stations whose data are compiled by the India Meteorological Department (IMD). On the basis of 60-year rainfall data (1901-1960) for about 3,000 raingauge stations distributed more or less uniformly all over the country, the average annual rainfall of the contiguous Indian area (outside Pakistan and Bangladesh) has been estimated as 1,180 mm. Very few countries of the world receive an average annual rainfall of this magnitude. About 75 per cent of the annual total is received during the south-west or summer monsoon season of June to September. However, this distribution varies widely from one part of the country to another (see figure I).

On the basis of distribution of rainfall and other meteorological parameters such as temperature, pressure, humidity and winds, the contiguous area of the country has been divided into homogeneous meteorological subdivisions. These subdivisions correspond more or less to political subdivisions of the country, of which there were 31 as of 1 January 1971 (see figure II). Mean annual rainfall of these subdivisions has been worked out on the basis of all available rainfall data of stations in each of these subdivisions for the 80-year period from 1891 to 1970 and these data are given in table 1 together with data of other useful statistical parameters, such as standard deviation (SD) and coefficient of variation (CV). It has been found that among the 31 contiguous subdivisions of the country mean annual rainfall is highest in coastal Karnataka and lowest in West Rajasthan. The coefficient of variation is lowest for north Assam and highest for Saurashtra and Kutch.

3. Year-to-year variation of rainfall

Apart from spatial variation of rainfall, the year-to-year variation over the Indian region as a whole was also studied using the 80-year data. The coefficient of variation, which is a statistical measure of inter-annual variation, was worked out to be 9.5 per cent, thereby indicating the stable nature of Indian rainfall. Further, it was observed that by and large in 75 per cent of the years, annual rainfall of the country was normal (i.e. departures within $\pm$ 10 per cent of the mean annual rainfall). Out of the 80 years examined, excessive rainfall (i.e. departures greater than + 10 per cent of the mean annual) was experienced in 11 years, while deficient rainfall (i.e. departures less than – 10 per cent of the mean annual) was observed in 9 years. The year 1917 was the wettest year recorded, when the annual rainfall was 25 per cent in excess of normal, while the succedding year, 1918, was the driest, when the annual rainfall was 20 per cent in deficit.

4. Tropical disturbances and their role in the distribution of rainfall

During the monsoon period, tropical disturbances, i.e. depressions/cyclonic storms, cause widespread and intense rainfall in areas over which they travel and at the same time these disturbances deprive some other areas of their usual share of monsoon rainfall. During the 60-year period, the Indian land area was traversed by 567 depressions and cyclonic storms. Of these disturbances, 477 and 36 entered the country through the east and west coasts respectively and the remaining 54 were land depressions. A study was carried out to examine whether the frequency of tropical disturbances traversing the country in different years had any effect on the average annual rainfall of the country as a whole. It was found that the passage of a larger number of those disturbances during a monsoon season did not always indicate incidence of more rainfall over the country. However, the contribution of these distur-

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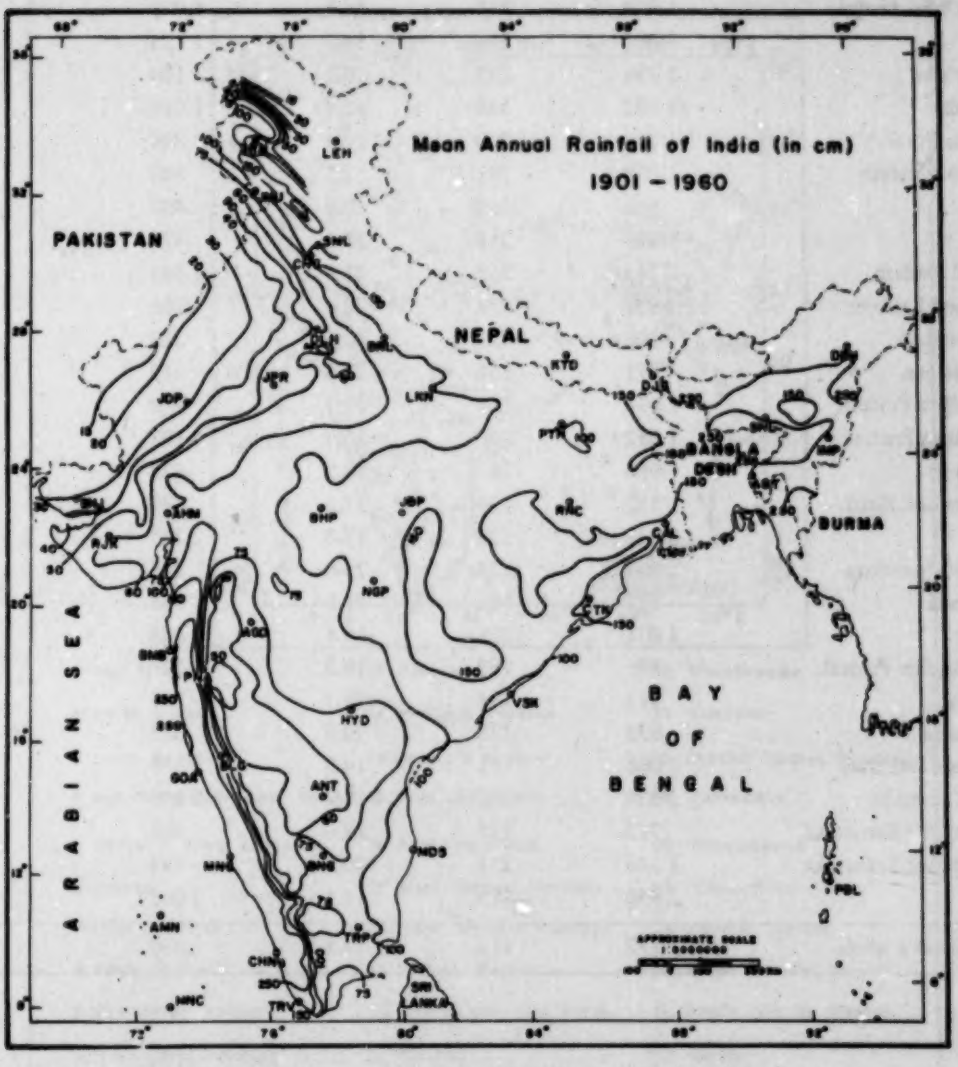

Figure I. Mean annual rainfall of India, 1901-1960 (in cm)

Table 1. Statistical parameters of rainfall for contiguous subdivisions of India, 1891-1970

Name of the meteorological subdivision as of 1 January 1971	*Mean annual rainfall (mm)*	*Standard deviation (mm)*	*Coefficient of variation (percentage)*	*Mean monsoon rainfall (mm)*	*Monsoon rainfall as percentage of annual*
North Assam	2 280	263	11.5	1 497	66
South Assam	2 833	325	11.5	1 808	64
Sub-Himalayan West Bengal	2 798	418	14.9	2 191	78
Gangetic West Bengal	1 419	211	14.9	1 078	76
Orissa	1 486	211	14.2	1 125	76
Bihar Plateau	1 336	175	13.1	1 104	83
Bihar Plains	1 192	188	15.8	1 016	85
East Uttar Pradesh	1 016	200	19.7	894	88
West Uttar Pradesh	1 030	191	18.5	883	86
Haryana	548	153	27.9	457	83
Punjab	621	212	34.1	479	77
Himachal Pradesh	1 745	369	21.1	1 345	77
Jammu and Kashmir	997	223	22.4	506	51
West Rajasthan	303	122	40.3	270	89
East Rajasthan	671	181	27.0	615	92
West Madhya Pradesh	1 034	204	19.7	940	91
East Madhya Pradesh	1 352	209	15.5	1 193	88
Gujarat	966	285	29.5	922	95
Saurashtra and Kutch	522	194	37.2	489	94
Konkan	2 935	523	17.8	2 765	94
Madhya Maharashtra	1 004	235	23.4	853	85
Marathwada	827	205	24.8	701	85
Vidarbha	1 071	208	19.4	938	88
Coastal Andhra Pradesh	996	182	18.3	577	58
Telangana	912	194	21.3	745	82
Rayalaseema	678	138	20.3	382	56
Tamil Nadu (Madras)	1 006	141	14.0	345	34
Coastal Karnataka	3 329	506	15.2	2 897	87
North Interior Karnataka	712	135	19.0	467	66
South Interior Karnataka	1 144	231	20.2	744	65
Kerala	2 950	415	14.1	2 005	68
Indian area as a whole	1 172	112	9.5	890	76

1 Bay Islands	12 Punjab	23 Marathwada
2 North Assam	13 Himachal Pradesh	24 Vidarbha
3 South Assam	14 Jammu & Kashmir	25 Coastal Andhra Pradesh
4 Sub-Himalayan West Bengal	15 West Rajasthan	26 Telangana
5 Gangetic West Bengal	16 East Rajasthan	27 Rayalaseema
6 Orissa	17 West Madhya Pradesh	28 Tamil Nadu
7 Bihar Plateau	18 East Madhya Pradesh	29 Coastal Mysore
8 Bihar Plains	19 Gujrat Region	30 North interior Mysore
9 East Uttar Pradesh	20 Saurashtra and Kutch	31 South interior Mysore
10 West Uttar Pradesh	21 Konkan	32 Kerala
11 Haryana	22 Madhya Maharashtra	33 Arabian Sea Islands

Figure II. Meteorological subdivisions of India as on 1 January 1971

bances to the water resources of the Ganga and the Godavari river basins has shown that these disturbances contribute about 8 to 12 per cent of the mean annual rainfall of these two basins.

(a) *Absence of tropical disturbances and rainfall distribution*

The influence on Indian rainfall when these disturbances are totally absent from the Indian scene was also studied. This study has shown that over north Indian plains the average deficiency in rainfall during the principal monsoon months of July and August could be of the order of 19 per cent and 17 per cent respectively. The subdivisions of the country worst affected by the absence of these disturbances were found to be: (i) Orissa, (ii) West Rajasthan, (iii) East Rajasthan, (iv) Gujarat, (v) Saurashtra and Kutch.

(b) *Rainfall distribution along the east coast on the day tropical disturbances cross the coast*

The distribution of rainfall along the east coast of India was studied when these disturbances cross the coast. It was found that in the case of the Orissa and Andhra Pradesh coasts, the day on which a tropical disturbance moved inland, the heavy rain centre of the storm was located about 80 to 160 kms to the left of the storm track between the coast and 80 kms inland. In the case of the Tamil Nadu coast, the heavy rain centre was found to be located much closer to the storm track. In other words, the heavy rain centre lies within 80 kms of the storm track on its left side.

5. Floods and droughts

The rainfall of the country, though less variable from year to year, is highly variable from month to month. This seasonal variability in Indian rainfall is responsible for causing floods and droughts in different parts of the country almost every year.

(a) *Incidence of floods*

From an examination of the highest flood data of all the major rivers of the country, it was found that 11 major rivers of the country at about 22 sites recorded the highest floods which were 5 to 18 metres above their respective danger levels. The highest ever recorded flood in India was 18.1 metres above the danger level and this happened on the Teesta and Anderson Bridge in north Bengal on 4 October 1968. This flood was caused by the intense rainfall associated with the breaking up of a Bay depression over sub-Himalayan West Bengal during the period 3 to 5 October 1968. The next highest flood occurred in the Narmada at Garudeshwar in Gujarat on 6 September 1970. On this occasion the Narmada was 17.9 metres above the danger level. This flood was caused by the incidence of very heavy rainfall between 5 to 7 September over the Narmada basin in association with the passage of a westward-moving land depression. Table 2 gives some data on the worst floods experienced in India from 1954 to 1978.

(b) *Incidence of droughts*

Dhar and others have examined the drought-years experienced in India from 1891 to 1970 based on rainfall deficiency. They delineated the areas of the country which were susceptible to frequent droughts. It was observed that there were nine years in which a large number of contiguous subdivisions of the country experienced moderate to severe drought conditions. Table 3 gives details of the worst drought years. The subdivisions worst affected by these droughts were generally found to be those which lie to the west of longitude 80°E. Further, it was noted that there was no systematic time interval between any two successive drought years but on an average one of these worst drought years can be expected in a decade. It was further observed that the subdivisions of the country liable to frequent droughts are those whose mean annual rainfall is less than 1,000 mm. During the period 1891 to 1970 the drought of 1918 was the most severe from the consideration of areal extent, while from the rainfall deficiency point of view the drought of 1899 was the worst.

(c) *Heavy rainfall stations*

Station rainfall in India in a year varies from about 80 mm in Rajasthan to about 11,000 mm or more at Mawsynram in Meghalaya. A study was undertaken with a view to identifying which stations in the country received heavy rainfall. A heavy rainfall station was considered to be one whose mean annual rainfall was 5,000 mm or more. This study has shown that there are about 14 stations in the country whose mean annual rainfall is 5,000 mm (i.e. 200 inches) or more. Of these 14 stations, 4 are located in north-east India (Denning, Buxa, Cherrapunji and Mawsynram) and the remaining 10 stations (Matheran, Mahabaleshwar, Amboli, Gaganbawada, Agumbe, Bhagamandala, Pulingoth, Makut, Neriamangalam and Peermade) are located in the Western Ghats of peninsular India. It has also been observed that Mawsynram station, which is located 16 kms to the west of Cherrapunji, is the rainiest station in India, receiving annually on an average about 1,190 mm of rain more than Cherrapunji. It has also been observed that the world's highest record rainfall for a 4-day duration was broken by Cherrapunji during September 1974. Cherrapunji otherwise holds the world record for the highest rainfall for durations of 15 days to 2 years. The world's highest point rainfall envelope curve for different durations follows the equation $R = 76.9\ D^{0.475}$, where R is the rainfall in inches and D the duration in days. In the case of Cherrapunji, the enveloping rainfall curve was found to have the equation $R = 49\ D^{0.485}$.

6. Design storm studies

There are 66 major river basins in the country. Systematic long-period rainfall data of some of the basins where water resources projects are being planned

Table 2. Some of the highest floods experienced in India, 1954-1978

River	*Gauge site*	*State*	*Level of maximum flood above danger level (metres)*	*Date and year*
Jaldhaka	Nagarkata	W. Bengal	7.75	1954
Mahi	Dam axis	Gujarat	11.80	8 Sept 1973
"	Vasaol Gauge Site	"	12.79	8 Sept 1973
Narmada	Mortakka	Madhya Pradesh	10.96	17 Sept 1961
"	Garudeshwar	Gujarat	17.91	6 Sept 1970
Subarnarekha	Jamshedpur	Bihar	8.72	12 Oct 1973
"	Jamsalaghat	Orissa	7.62	13 Oct 1973
Tapi	Bhusaval (Burhanpur)	Maharashtra	11.08	1968
"	Savankheda	"	7.60	16 Sept 1959
"	Gidhade	Gujarat	8.53	1968
Teesta	Anderson Bridge	W. Bengal	18.10	4 Oct 1968
"	Coronation Bridge	"	10.65	Oct 1968

Table 3. Worst drought years of India, 1891-1970

Drought year	*Number of sub-divisions affected*	*Total area of the country affected due to drought (percentage)*	*Average rainfall in the drought-affected area as per cent of mean monsoon rainfall*	*Time interval between two successive droughts (Years)*
1899	22	70	51	-
1901	12	38	69	2
1905	15	47	75	4
1918	23	73	54	13
1920	14	51	67	2
1941	12	42	71	21
1951	16	56	71	10
1965	14	54	68	14
1966	13	48	76	1

have been analysed with a view to obtaining the following: (i) space-time distribution of storm rainfall; (ii) estimates of design storm up to different dam sites using different techniques; and (iii) estimates of probable maximum rainfall (PMP) of long-period stations with a view to preparing generalized PMP charts.

(a) *Design storm magnitudes as percentage of maximum one-day, two-day and mean annual basin rainfall*

The design storm studies of a number of river basins of India (see table 4) have revealed that in the most severe three-day rainstorm about 50 per cent of basin rainfall is obtained on the heaviest of the three days, 30 per cent on the second heaviest day and only 20 per cent on the third day. Further, it was observed that three-day maximum basin rain depths vary from 13 to 42 per cent of the respective mean annual basin rainfall. In the majority of basins, however, this ratio varies from 20 to 29 per cent, thereby showing that more than one fifth of the annual rainfall over a basin can occur in the course of three days.

(b) *Spillway design storm magnitudes in different rainfall regions*

A comparative spillway design storm study was carried out for three north Indian river basins; the Mahi, the Betwa and the Subarnarekha. These basins, although located in the same latitudinal belt of 20 to 25°N, are located in different rainfall regions of north India. This study has shown that the magnitude of spillway design storm for different durations is independent of the mean annual rainfall of the region in which the problem basin is located. River basins in the low rainfall regions can have higher design storm magnitudes when compared with basins located in high or rainfall regions of the country.

7. Rainstorm analysis

There have been about 1,000 major rainstorms from 1891 to the present which have occurred in different parts of the country. Of these, some of the most severe rainstorms have been analysed in recent years. Important findings obtained from this analysis are given below.

(a) *Areal rain depths from most severe rainstorms*

Analysis of severe rainstorms experienced in India from 1880 onward has revealed that two rainstorms gave the highest areal rain depths for different areas and durations: (i) September 1880 over north-west Uttar Pradesh and (ii) the rainstorm of July 1927over Gujarat (see table 5). Comparing the areal rain depths obtained from these rainstorms with similar rain depths from tropical United States of America, it has been seen that the above two rainstorms gave higher areal rain depths for areas of 12,950 sq kms (5,000 square miles) and above for one-day duration and for all the areas up to 129,500 sq kms (50,000 sq miles) for two and three-day durations. In the absence of rainstorm data from other tropical regions of the world, it cannot be said whether these two rainstorms are the most severe rainstorms of the world.

(b) *Area-intensity relationship of storm rainfall*

The maximum intensity of rainfall in a storm occurs over a small area. As we move away from the storm area the rain intensity decreases sharply towards the periphery of the storm as a result of which the average intensity over a large area within the storm becomes less with the increase in storm area. From an analysis of a large number of rainstorms in different parts of north India (north of Latitude 20°N), the area-intensity relationship of storm rainfall has been derived as $\frac{\bar{P}}{Pm} = e^{-KA^n}$, where $\bar{P}$ is average rainfall for an area of a given size A and Pm is the maximum point rainfall experienced in the storm area, K and n being constants whose values vary with the duration of the rainstorm. The values of the K and n for different durations are as follows:

Rainstorm duration	*K*	*n*
1-day	0.0016	0.6614
2-day	0.0018	0.6306
3-day	0.0030	0.5691

Using the above relationships, areal rainfall can be estimated for small size basins in north India from the observed maximum point rainfall in the problem basin.

8. Maximum rainfall and probable maximum rainfall over north Indian plains

(a) *Maximum rainfall for low return periods*

Maximum point rainfall data of different return periods are often required for design of small hydraulic structures. Dhar and Kulkarni have developed a simple technique of estimating maximum one-day rainfall for low return periods of 2, 5, 10 and 25 years from the mean annual rainfall of the station concerned. Nomograms have been prepared for each of the subdivisions of north India with the help of which maximum one-day rainfall for any return period from 2 to 25 years for any station can be directly estimated from the mean annual rainfall of the station concerned. Normally, mean annual rainfall is available in meteorological tables, school atlases or geography books and therefore no special effort is required to find out low-return period rainfall for any station in north Indian plains using the above technique.

(b) *Probable maximum rainfall*

Probable maximum precipitation (PMP) has been defined as the greatest depth of precipitation for a given duration that is physically possible over a basin or a

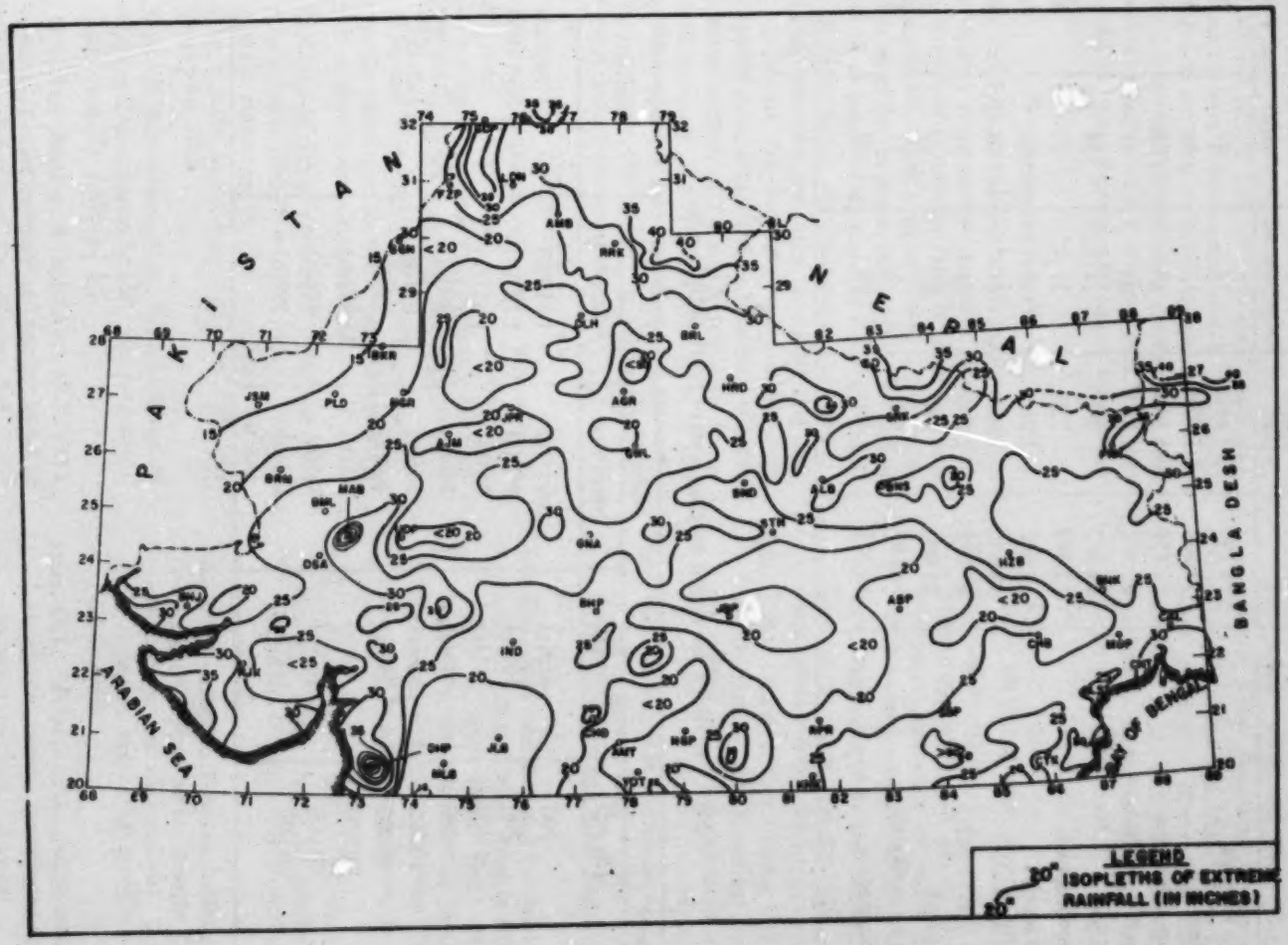

Figure III. Generalized chart of one-day extreme rainfall over north India (in inches)

Table 4. Design storm studies conducted for various river basins of the country

Name of the basin	*Area (sq km)*	*Mean annual rainfall (mm)*	*Ratios*		
			3-day rainfall as percentage of mean annual	*1-day rainfall as percentage of 3-day*	*2-day rainfall as percentage of 3-day*
Yamuna up to Tajewala	11 137	1 460	13	42	78
Beas up to Pong	14 504	1 470	17	44	81
Baitarani up to Akhyapada	10 878	1 560	29	52	91
Lower Mahanadi up to Tikkarpara	42 476	1 450	24	41	79
Bhima up to Ujjani	14 867	940	22	54	79
Godavari up to Gangapur	15 540	750	27	52	81
Krishna up to Sangli	9 842	1 360	20	56	80
Krishna up to Alamatti	34 182	1 240	21	58	88
Krishna up to Narayanpur	47 725	1 090	21	58	89
Mahi up to Kodana	25 486	850	42	49	82
Subarnarekha up to Ghatsila	14 162	1 450	16	71	85
Betwa up to Rajghat	16 317	1 160	27	43	78

Table 5. Envelope rain depths for plain areas of North India, in mm.

Area		*Duration*			*Remarks*
(Sq km)	*(Sq mi)*	*1-day (mm)*	*2-day (mm)*	*3-day (mm)*	
259	100	813(a)	1 029(a)	1 219(b)	(a) = Rainstorm of Sept 1880
1 295	500	765(a)	983(a)	1 107(b)	
2 590	1 000	711(a)	935(a)	1 031(b)	
12 950	5 000	478(a)	726(a)	790(b)	(b) = Rainstorm of July 1927
25 900	10 000	366(a)	564(a)	671(b)	
51 800	20 000	259(a)	409(a)	546(b)	
77 700	30 000	203(b)	355(b)	483(b)	
103 600	40 000	180(b)	315(b)	428(b)	
129 500	50 000	160(b)	279(b)	389(b)	

drainage area. Studies of PMP are useful for the design of hydraulic structures, for which safety cannot be risked. Hershfield has examined this aspect of rainfall and has given a statistical method which has been recommended by the World Meteorological Organization. In India a generalized PMP chart of one-day duration (see figure III) has been prepared on the basis of 60 to 80-year rainfall data of more than 1,000 long-period rainfall stations for the plain areas of the country from latitude 20°N to 32°N and longitude 68°E to 80°E. It is seen from this generalized chart that the PMP estimates over north India vary from about 370 mm (15 inches) to about 875 mm (35 inches) for one-day duration.

9. Concluding remarks

By and large, annual rainfall throughout India is received during the monsoon months of June to October. Its unequal distribution both in space and time is responsible for causing severe floods and droughts year after year. For the proper utilization of this natural resource, it is necessary to study its space-time distribution in depth so that the water can be harnessed for agricultural, industrial and other nation-building activities. Considering this and using the available long-period rainfall data, certain studies have been initiated in the Indian Institute of Tropical Meteorology, Poona 5, a brief summary of which has been given in this article. It is hoped that these studies may be quite useful to design engineers and planners for the development of vast water resources of this country.

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THE VALUE OF A LONG-RANGE WEATHER FORECAST FOR THE WEST AFRICAN SAHEL*

Introduction

This study is designed to assess the political, economic, social, and environmental implications of a reliable long-range weather forecast. The impact that such a forecast might have can be seen as a function of numerous variables such as the level of economic development, level of analysis, type of political and economic system, and the nature of the forecast among others. To make this a manageable study, the West African Sahel, a climatic zone with persistent droughts between 1968 and 1973, has been chosen as a case study.[1] The region directly affected by the drought encompasses parts of at least the following six countries, Senegal, Mali, Mauritania, Upper Volta, Niger, and Chad, whose populations total about 25 million. About 6 million inhabitants and about 25 million cattle were in the region directly affected by the drought. Attention was focused on the devastating year of 1973, in that it has been estimated that more than 100,000 human deaths and up to 40 per cent of the livestock deaths occurred then. A reconstruction of the grazing situation using agricultural, meteorological, and social data was undertaken to show what actually happended to livestock and to the rangelands in that year (Glantz, 1975).

The first part of the paper presents a brief overview of the Sahelian setting. For the second part, it was assumed that an accurate forecast of monthly averages of precipitation and temperature for the Sahel for the entire growing season (June through October) was available by October of the preceding year. The Governments would then have six or seven months available between the time of the forecast and the time for spring planting to prepare for the impact of the forecast anomaly. The value of making such a hypothesis (i.e. a perfect forecast) lies in determining the theoretical upper boundary of flexibility in the social systems being studied.

Respondents in such disciplines as range science, meteorology, political science, economics, anthropology, and medicine were asked what they would have done in the Sahel if they had accurate rainfall and temperature information for the future six months in advance of the beginning of the 1973 growing season. No restrictions were placed on the proposals respondents were asked to make, in order to encourage them to offer the widest possible range of choices. They were advised that an analysis would be undertaken later to assess the political, economic, social, and environmental implications of those suggested choices.

2. The Sahel

The Sahel has been defined by different authors in terms of vegetation (e.g. UNESCO, 1974), geography (e.g. Stebbing, 1973), and rainfall (e.g. Tanaka and others, 1975). In the present study the Sahel is considered to be the region of West Africa that receives 200 - 600 mm of annual mean rainfall (see figure I). It is bordered on the north by subdesert (100-200 mm) and to the south by the Sudan vegetation zone (600-900 mm). The mean 400-500 mm isohyets have been generally accepted as a boundary range north of which only irrigated crops should be grown. However, this boundary has been transgressed during periods of above-average rainfall. Rainfall in the Sahel occurs during a four to five-month period between as early as June and as late as October. The mean rainfall in the northernmost areas of the Sahel reaches a maximum in August.

The region is arid to semi-arid, and in such a climate the interannual precipitation variability is high. Therefore, meteorological as well as agricultural droughts are to be expected as part of the climate regime (e.g. Riehl, 1954; Landsberg, 1975). What is not known in advance about the droughts, however, is their timing, duration, location, and intensity (Davy, 1974).

A characteristic of the region is the relatively steep mean annual precipitation gradient, about 300 mm/100 km for the western part of the Sahel near the Atlantic Ocean (Cocheme, 1968; Riehl, 1954). As a World Meteorological Organization report noted, "It is in these areas of steep gradient that large fluctuations of rainfall occur if the pattern of global circulation shifts only slightly on the earth's surface" (WMO, 1974). A slight shift of the Intertropical Convergence Zone (ITCZ) toward the equator means a shift of the precipitation isohyets in that direction. When the ITCZ does not reach far enough north, the rains fail. If the rains fail for more than one season, the result is often widespread destruction of the rangelands caused by an over-concentration of animals near sources of permanent water, a con-

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1 A second case study, "Spring wheat in Saskatchewan, 1974," was also undertaken but will not be discussed in this paper.

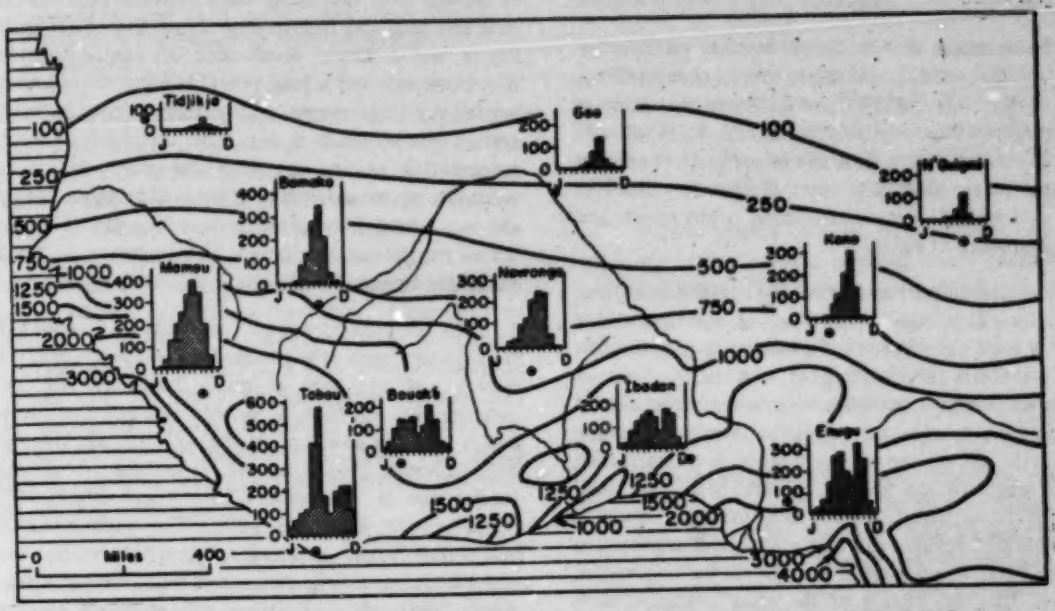

Figure I. Mean annual and mean monthly rainfall in West Africa. Rainfall in millimeters. From Thomas and Whittington (1969).

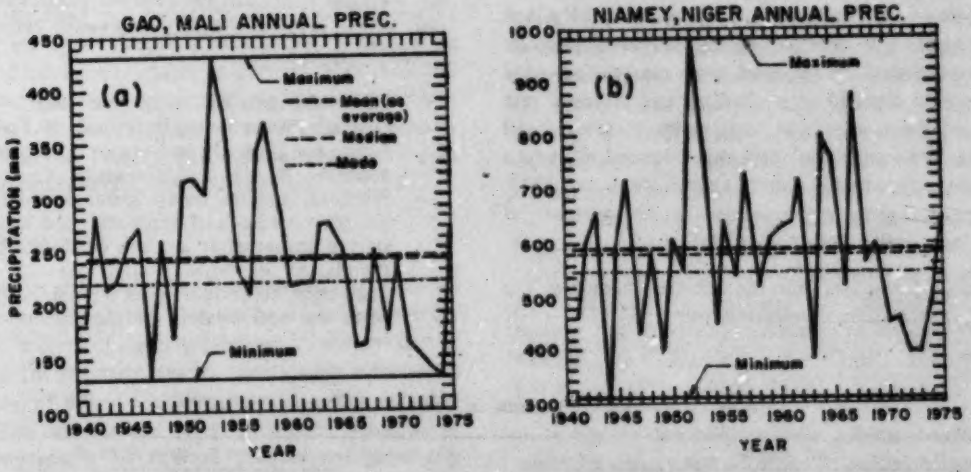

Figure II. Annual precipitation at (a) Gao, Mali, and at (b) Niamey, 1940–1975

comitant reduction in available forage, widespread migrations, malnutrition and death, as was the case in 1973.

Precipitation in the Sahel depends on thunderstorm activity, which occurs along disturbance lines (e.g. Riehl, 1954; Davy, 1974) and produces variations in precipitation within relatively small areas (e.g. Cocheme, 1968; Horowitz, 1972). It is also important to note that the value of the rainfall is often decreased by the high level of potential evapotranspiration, wind speed, and the high amount of runoff.

Drought definitions can be objectively divided into at least two categories: meteorological, and agricultural (Palmer, 1964; Saarinen, 1966). Meteorological drought can be defined as occurring at that time when the amount of precipitation is less than some percentage of the long-term to seasonal vegetation development. The distribution and timing of precipitation is crucial during certain stages of the specific growth cycles of cereal grains such as wheat, millet, and sorghum. Thus, a meteorological drought can take place but it might prove to have little or no adverse impact on the vegetation, provided that the timing of the rains coincided with vegetation growth needs. It is often difficult to distinguish between a meteorological drought and a dry spell. With respect to the American agricultural scene, most farmers do not consider a dry spell a drought until the moisture shortage has seriously affected the established economy of the region (Palmer, 1964). This may well apply to other regions of the world. Another example of the problem of defining droughts is the Ekrafane ranch in the Niger. An observer standing in the middle of the ranch would have considered the lack of precipitation a drought. It was suggested recently that there should be at least two components to a definition of drought - a physical and a social one (Glantz, 1976a). A mix of dry spells, meteorological droughts, and agricultural droughts occurred at various times and places in the Sahel between 1968 and 1973, but their impacts were worsened by the pressure of populations, both human and animal.

Table 1 suggests that the climate situation in the Sahel has always been a precarious one.

Normal, defined as mean rainfall, seldom occurs in the Sahel (Katz and Glantz, 1977). What is perceived to be normal is in fact above the long-term mean rainfall. Arid and semi-arid regions have a high degree of variability in, and a skewed distribution of, annual precipitation expressed over a long period in a few above-average rainfall years interspersed with a larger number of below-average rainfall years. In Figure II, the charts of annual precipitation at two locations give some idea of the variability in annual precipitation in this region. As one can see, "normal" conditions, i.e. values of rainfall near the mean, prevailed in only a few years out of the 35 (Katz and Glantz, 1977).

In addition to rainfall variability and other physical factors such as wind speed and evapotranspiration, human activities such as animal husbandry and land management practices have been suspected of having had a deleterious effect on the soil (e.g. Le Houréou, 1975; Glantz, 1976b) as well as on the precipitation mechanisms in the region (Charney and others, 1975; Schnell, 1974; Otterman, 1974). The recent reduction in available grazing area as a result of the drought coincided with a time when expanded herds were in need of greater availability of forage and water. It has been recognized, however, that the droughts have only tended to exacerbate a situation in which ecological deterioration was already well in progress (e.g. Clyburn, 1975; FAO, 1974).

3. Questionnaire response and analysis

About forty years ago, Carr (1939), writing about international politics in the interwar years, called attention to the need to distinguish between "what is" and "what ought to be":

> "The antithesis of utopia and reality – a balance always swinging towards and away from equilibrium and never completely attaining it - is a fundamental antithesis revealing itself in many forms of thought. The two methods of approach - the inclination to ignore what was and what is in contemplation of what should be, and the inclination to deduce what should be from what was and what is - determine opposite

Table 1. Previous extremes of rainfall in Zone 2 (Sahel).*

High rainfall		*Low Rainfall*	
Years	*Rainfall each year as percentage of 1931-1960 mean*	*Years*	*Rainfall each year as percentage of 1931-1960 mean*
1929-1931	109, 106, 121	1912-1915	85, 55, 78, 94
1952-1955	117, 116, 114, 108	1940-1944	80, 82, 76, 101, 73
1957-1962	112, 106, 105, 107, 102, 106	1947-1949	83, 93, 64
		1968-1973	72, 98, 97, 74, 69, 65

* Zone 2 rainfall stations are Niamey and Zinder in the Niger and Sokoto, Kano, and Maiduguri in Nigeria. Data from National Academy of Sciences (1975).

> attitudes toward every political problem. 'It is the eternal dispute,' as Albert Sorel puts it, 'between those who imagine the world to suit their policy, and those who arrange their policy to suit the realities of the world.'"

Applying this distinction to the area of international development programmes, one might suggest that development specialists (including government decision makers) could be divided into these two categories. One group influenced by the Western experience, while emphasizing "the need for integrated development" and advocating "the involvement of local rural populations in problem definition and solution," often failed to establish "mechanisms which might allow for the integration of rural populations into the development process" (e.g. Sy, 1968). Another group suggested that the traditional system be taken as the basis for development and that projects be built upon the existing cultural, political, economic and environmental subsystems (e.g. Warren, 1976).

Awareness of the gap between the two antithetical views is neither new nor has it been confined to the area of international development (Morgenthau, 1969; Perin, 1970; Papanek, 1973). Yet, as a heuristic device, such a dichotomy could prove valuable in the search for an understanding of the real as opposed to the imagined social value of weather information in a developing region like the Sahel.

The following discussion is divided into two parts: "what ought to be" and "what is." The former briefly presents the comments of various respondents on how they might have responded to a reliable forecast of monthly averages had such a forecast been available six months in advance (as early as October 1972) and had there been no constraints on making their suggestions operational. The latter section considers their comments in the light of existing political, economic, cultural, and environmental constraints in the Sahel.

(a) *"What ought to be"*

Knowing the reduction in precipitation six months in advance, the Sahelian Governments could assess the rangeland's carrying capacity, defined as the amount of grazing stock that the pasture can support without deterioration of either the pasture or the stock (Boudet, 1975). The lead time of six months or so would allow the Governments to activate programmes previously developed to minimize overgrazing and its implications. Governments could set up an animal stocking rate quota and cull the herds accordingly in order to meet the needs for genetic improvement and for the eventual reconstitution of the herds for the postdrought period. This would reduce pressures on the usually overstocked pastures. Governments could also seek to ensure rangeland preservation by establishing range reserves from which cattle would periodically be excluded, on some predetermined rational basis. The culled cattle could be sold; slaughtered for either immediate consumption, freezing, or drying; or exported to regional markets while they were in relatively good condition.

Given the contention that it takes five head of cattle to support one pastoralist (Brown, 1971), herders could be advised to send "surplus" family members to the south or to the coastal States in search of cash employment. This would make possible the removal of additional animals from the rangelands.

With a reliable forecast, better planting schedules could be devised so that peasants could conserve their grain and labour. The Governments could purchase and store fast-maturing grain for future distribution, thus enabling the population to consume the relatively long-cycle grain varieties. The purchased and stored grain could then be used for planting in the more reliable rainfall areas.

Government-sponsored price controls could be used to discourage grain hoarding by speculators and to stimulate pastoralists to sell their excess livestock before their condition deteriorated. Surveillance teams could be set up to monitor the state of health of the population and to run nutritional programmes. Governments could purchase grain for storage in advance to avoid panic buying during drought.

Sahelian States could also seek international assistance in advance of the food shortages. Donors would be in a better position to plan their relief operations to guarantee the timely flow of relief supplies into the affected areas. (This would require Sahelian Governments to establish a network of regional warehouses, a network of grain distribution, and a network for monitoring the distribution of that grain.) Public awareness of the forecast would serve as a drought alert for the affected States and for the international community. It would make it possible to pressure Sahelian Governments to take effective action to minimize the impact of the forecast drought. Until now, many Governments and non-governmental organizations have been reluctant to intervene in the internal affairs of a sovereign State. It is hoped that national leaders would be influenced by national and international public opinion not to withold assistance to drought victims, as was the case in Ethiopia and in Chad in the early 1970s (Shepherd, 1976; DuBois, 1974).

Finally, the building and repairing of earthen dams could be undertaken in order to cultivate land around the dam sites. Fodder production schemes would be undertaken in the wetter south or in irrigated areas. Either the fodder would then be shipped to the feedlots or to central locations in the interior, or the excess cattle would be removed to these areas.

(b) *"What is"*

Of all the possible crises confronting the Sahelian States, it has been suggested that political instability has

been the most important one (Lofchie, 1971). Perhaps it is the political circumstances that explain in part why existing scientific information is not being used for the benefit of society. Such existing information includes an awareness of the negative impacts of deforestation, of indiscriminate borehole construction, of range mismanagement practices, of the lack of economic rationalization of the livestock herds, and the like. Experts had proposed solutions to these problems long before the occurrence of the recent extended drought. Yet, throughout the twentieth century, little has been done in a concerted way to implement this knowledge. Therefore, it cannot be automatically expected that additional knowledge derived from a yet-to-be-developed reliable technological capability, such as a long-range weather forecast of monthly averages, would be any more useful than the information that has been available for some time, but that has not been used.

In this section the "what ought to be" suggestions will be discussed in the context of the existing subsystems within the West African system.

It is widely accepted that an assessment of the carrying capacity of the ranges is a necessary but not a sufficient step in any attempt to retard the continual deterioration of the ranges. There appears, however, to be little agreement as to how such an assessment should be made. One expert has suggested the use of indicator plant species to determine range trend (Ayuko, 1975). Another noted that in tropical Africa, stocking rates had been "assessed on the sole basis of forage production of pastures" (Boudet, 1975). Yet another wrote that the quality as well as the quantity of the forage must be considered (Rivière, 1975). Such contraditions within the scientific community, while understandable, tend to create confusion for the decision makers in Sahelian as well as in donor States. Under these circumstances, Sahelian and donor State representatives either make no decision at all (i.e. inaction), which is a decision in favour of the *status quo*, or they consider all scientific recommendations to be of equal value and choose any one of those suggested.

Although a warning about the likelihood of drought might convince a Sahelian Government to issue a stocking rate statement and to determine which plan to pursue, there would be little or no assurance that anything could be done in the field to reduce grazing pressures on the Sahelian rangelands. For a periodically issued carrying capacity statement to be effectively used, there would be a need to overcome political, cultural, and economic constraints within these societies. For example, the Government would have to enact and enforce policies to control herd sizes and to accept the positive and negative ramifications of such actions: What will be done with the culled cattle? How will they be removed from the ranges? Which herd member will be culled? How will the water holes be controlled? How will the excess cattle be disposed of (marketed)? Who will pay for these and other similar operations? What compensation will be herders receive? Would the pursuit of such policies tend to alienate further, for example, members of the pastoral community?

The recent Sahelian drought heightened public awareness of an ecological situation about which many experts have been concerned for decades. It has been known since at least the beginning of the century that one of the major factors leading to rangeland deterioration, in developed as well as in developing countries, is that of too many cattle on the rangeland. Yet, following each drought situation, there has been a tendency to forget about instituting rangeland reforms. As a result, recommendations made following the recent drought have been similar to those following other African droughts during this century (Glantz, 1976).

There are several other obstacles to attempts to achieve an economic rationalization of livestock production in the Sahel. Although it has been suggested that pastoralists have increasingly turned away from traditional livestock practices (Sabry, 1972), there is evidence that they are returning to the Sahel and rebuilding their herds with little regard for optimal economic rationalization based on herd structure and size (Laya, 1975). This tends to emphasize a return to what Khalifa and Simpson (1972) termed, from a Western view, a perverse supply/demand relationship that often appears in nomadic societies, that is, "in such non-market oriented communities, the money needs of the people are so limited that any rise in the price of their products inevitably leads to a curtailment in supply." Pastoralists often sell only that number of cattle that will make it possible for them to meet some fixed "target" income need, such as for the payment of a government tax. It is, therefore, suggested that the economic rationalization of livestock production in the Sahel will have to be a compromise between the Western expert's perceived optimization of livestock production and the herder's traditional desire to maintain as large a herd as possible (Ware, 1975).

Other constraints on the rationalization of livestock production also exist. For example, although the culling of livestock was strongly suggested by several respondents, it could be shown that the existing transportation and marketing infrastructures in the Sahel tend to act as constraints on the realization of such idealistic suggestions.

Much of the transportation network in West Africa is a legacy of the colonial era and was built by and for the colonial powers with export and self-interest in mind (Morgan and Pugh, 1969). A good example of this is that transportation outlets from land-locked French-speaking States avoid the potentially more efficient routes through English-speaking coastal States (Thriscutt, 1972). Furthermore, neither Niger nor Chad possesses a railway system within its borders.

With respect to the transport to market of culled animals, it was suggested that the Sahelian transport

system in general was incapable of efficiently moving live animals (McLeroy and Konnerup, 1969). For example, some of the problems encountered on the Abidjan-Niger line (to Upper Volta) were as follows: long delays due to customs or *en route* malfunctions, too few cattle cars (i.e. the unavailability of cattle cars for weeks at a time), poorly ventilated cars, and 4-7 days in transit without food or water causing excessive weight loss as well as in-transit livestock deaths (Bishop, 1972). Many of these problems are management-related and occur during the interdrought as well as the drought years.

Road construction projects have contributed to the economic decline of the rail system because new roads were not built to feed into them. The two modes of transport have, therefore, developed in competition with each other (Thompson, 1973). Yet, the trucking of livestock into and out of the Sahel has its own drawbacks. In addition to the long distance, the small loads, the absence of back hauls, and dispersed populations, other obstacles include the high cost of fuel, long delays due to customs and tributes to villages along the transport route, and poor road maintenance (Bishop, 1972).

It should also be mentioned that a large percentage of the cattle make the entire trek on foot and arrive at the major consuming centres "as dying animals with a 15 per cent live weight loss" (McLeroy and Konnerup, 1969).

Marketing is considered to be "the greatest immediate constraint to improvement of the cattle industry" (McLeroy and Konnerup, 1969). In addition to the rational marketing of excess cattle in the Sahel, there exist other problems such as those related to foreign exchange, stagnant and/or declining costs of living, finding export markets, political instability, national self-interest (i.e. land-locked versus coastal States), and disease. While it is easy to suggest the slaughter of cattle for consumption, freezing or drying, or live exportation, one must wonder how such suggestions would be implemented given the minimal levels of development of the marketing infrastructure (Stryker, 1973).

Modern abbatoirs (slaughter houses) have contributed little toward improving the market structure and function in the Sahel (McLeroy and Konnerup, 1969; Bishop, 1972). They have low levels of efficiency partly because of the Governments' pricing of meat products, a situation that has led to clandestine meat processing and a bypassing of the abbatoirs (Stryker, 1973). The poor transportation network has compounded the problem. The transport system's inadequacies for the shipment of chilled meat and live animals are compounded also by "the high utilization of offals (waste parts of butchered animals) and by-products on the African mass market" (McLeroy and Konnerup, 1969).

As part of any government effort to reduce grazing pressure on the rangelands, it was suggested that Sahelian Governments could identify adequate pastures and water using Landsat[2] imagery information (Rudd, 1974). This would depend on each Government's technical capability to analyse the satellite imagery and to communicate such information to the herders. With respect to conducting livestock inventories, a recent study on the application of remote sensing to rangeland management problems in the Sahel noted that, although solutions to range management may appear simple, the present state of the art is not fully suited to solving the problem (Bale and others, 1974). Such Landsat capability does not exist at this time, and when it does, there will be a need for aircraft and ground verification. In addition, a Landsat imagery capability would require a financial and technical capability that the overburdened Sahelian budgets would be hard pressed to supply.

It is important to mention that the spatial aspect of a reliable long-range forecast would be broad. Yet, given the nature of the rainfall distribution in the Sahel, this would mean that the forecast would be inapplicable for use at the local level (except, perhaps, for estimating export pressure, local rainfall probabilities, and the like).

In order to undertake a programme of prepositioning grain, national and regional planning would be required to determine optimal locations of needed storage facilities in the event of a forecast dry spell or drought. The recent infusion of drought relief into the Sahel highlighted many inadequacies in the storage network from the port areas of the coastal States to the interior of the Sahel (DuBois, 1974). Problems such as grain spoilage or loss because of inadequate storage facilities, the abundance of pests such as rodents (Fall, 1976), and corruption greatly reduced the effectiveness of the relief operation.

Given a forecast six months in advance, in theory the Sahelian Governments would be in a position to co-ordinate relief shipment to minimize bottle-necks in the transportation and storage networks. Yet, in reality, for the forecast information to be of major value, there would have to be a major improvement in the way grains are stored in the Sahel, in the port areas as well as in the interior. In fact, the recent drought only served to exacerbate the chronic food shortage that is expected to occur at the end of each dry season (FAO, 1962). As one expert noted, "the facilities for marketing, storage and preservation are in their infancy in West Africa" (Hodder, 1973).

Implementation of the new laws would run into immediate problems not only at the local level (Thomson, 1977) but also at the national level because of the lack of co-ordination among those government ministries and departments concerned with various aspects of range management (Baker, 1976). Jurisdic-

2 Landsat (Land Satellite) replaced ERTS (Earth Resource Technology Satellite) in 1975. The change was one of nomenclature only.

tional rivalry is only one of the major problems that exist within these bureaucracies. Other such problems are corruption, politicization of administrators, the low-skill levels of bureaucratic personnel, ideological and cultural rivalries, competition for scarce resources, and the general slowness of the bureaucracy. These problems, of course, are not unique to the Sahelian States (e.g. Aboyade, 1968).

It was suggested that excess cattle be removed to areas with more reliable rainfall, to temporarily irrigated zones, or to feedlots near beef-consuming areas. However, some of the obstacles to such suggestions are formidable: the tsetse fly, irrigation-related disease, and the cultivation of fodder crops.

The tsetse fly. The presence of the tsetse fly, responsible for trypanosomiasis among cattle, has resulted in minimizing cattle grazing in the south of the Sahel. Ormerod (1976) recently suggested that "cattle must be protected either by chemoprophylaxis or by the more effective method of keeping them away from the tsetse." Chemoprophylaxis can be applied periodically to suppress trypanosomiasis, but it has no impact on the sources of the infection. Furthermore, keeping cattle from the tsetse fly zone is not always possible and depends on grazing needs at the time.

Irrigation-related disease. Bilharzia (i.e., schistosomiasis), a chronic debilitating disease, has been a major problem in most irrigated regions in tropical Africa. If either temporary or permanent irrigation schemes were to be developed to minimize the impact of the forecast drought on cattle, it would be necessary for the Governments to attack either the cause of this disease (i.e. by an application of molluscicides) or its effect (i.e. by medical treatment for the afflicted).

Other diseases such as onchoceriosis (river blindness), parasites, and chronic malnutrition also tend to plague the Sahelian populations (Imperato, 1976). Many of these infectious diseases have hindered or blocked the development of new projects. In fact many new development projects have served to spread these diseases (Lambrecht, 1972).

Cultivation of fodder crops. The Governments could encourage cultivators in the wetter zones to convert some arable land to fodder production to feed the livestock of the pastoralists, their potential socio-economic antagonists. However, the conversion of agricultural land devoted to export crop production to fodder or food production would be no easy task, especially given that, "the strong political position of the exporting interests almost certainly accounts for the fact that their farms nearly always occupy the best arable areas" (Lofchie, 1975). (See also Berg, 1975; Mortimore, 1973.) Lofchie (1975) pointed this out as being one of West Africa's agrarian paradoxes: a stagnation or decline in agricultural production for internal needs with a simultaneous increase in agricultural production for export.

4. Summary

The Sahelian States are confronted by what might be termed a hydraheaded crisis composed of the following elements: (1) technical and institutional constraints (Hilling, 1973); (2) legitimacy, distribution, integration, and penetration crises (Pye, 1966); and (3) embryonic political institutions carrying the burdens of welfare and development and the implications of a rapid "transition from labour intensive to automated industrial systems" (Lofchie, 1971), "the perennial shortage of state revenue" (Wallerstein, 1971) among others.

These States will need the material support and encouragement of the international community to deal effectively with such internal crises. It is important to remember that recent attention was drawn to the Sahel only as a result of the implications of the recent extended drought and that, with a return to above-mean rainfall levels, interest in dealing with these chronic problems will dissipate (Baker, 1976).

It is important to remember that there are several limitations related to the collection, analysis, and validity of Sahelian data. For example, there is little reliable information on trade, agricultural production, marketing, size of livestock herds, or number of livestock deaths.

The "softness" of the Sahelian data make Carr's (1939) antithesis ("what is" versus "what ought to be") a particularly useful concept for making an analysis of the implications of a reliable long-range forecast. Its use enables researchers to focus on these two extreme views. This, in turn, tends to heighten an awareness of constraints that often blocks the attainment of benefits for society of a potential technological capability. Whatever the value of a perfect forecast for the Sahel might be, a less than perfect (but at present the only possible) probabilistic forecast would be of even less value.

This preliminary assessment leads to the tentative conclusion that, given the national structures in the Sahelian States in which a potential technological capability would be used, the value of a long-range forecast, even a perfect one, would be limited. It appears, however, that its value could be greatly enhanced if its implementation were to be coupled with the removal of the numerous social, political, and economic obstacles, some of which have been enumerated in the present paper. Required, for example, would be the need for national, regional, and international desire to implement potentially controversial policies such as the control of watering points, the establishment of range reserves, the determination of an operational carrying capacity, the development of an adequate marketing infrastructure, and the like.

Finally, the author suggests that this study offers another approach to assessing the implications for society of a potential technological capability. The approach is used to draw attention to the often implicit

assumptions concerning the potential benefits for society of new technology. Carr's antithesis should help to avoid undertaking a technological impact study solely from either a utopian standpoint, which takes little account of political and other obstacles, or from a reality standpoint, which excludes every element of utopia (Carr, 1939). Comments on the social value of technology as well as on the social value of development schemes have suffered too long from at least two major weaknesses that have also been attributed to post-war United States foreign policy. "The inability to distinguish between what is desirable and what is possible, and the inability to distinguish between what is desirable and what is essential." (Morgenthau, 1969).

Although a reliable long-range weather forecast is not yet possible, it may not even be desirable for many parts of the world until that time when some essential adjustments to existing social, political, and economic practices have been undertaken.

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FLOOD STUDIES LED TO NATIONAL FLOOD INSURANCE*

Floods have been a recurrent source of damage and distress for generations. In United States Geological Survey (USGS) Professional Paper 950, Editors G.D. Robinson and Andrew M. Spieker rank flooding second among geological hazards in causing damage (ranking behind expansive soils) and first in causing loss of life (10 times as many deaths annually as second-place earthquakes). Because of the importance of floods, not long after its 1879 formation, USGS turned its attention to measuring flood flows.

The survey initiated special flood studies in 1902 with the Passaic River flood in north-eastern New Jersey. The report was published in 1903. In recommending approval for publication, the authors' justification seems amazingly current: "The vested capital and community interests are large, and it is therefore desirable that the occurrence and progress of great floods in the drainage area be thoroughly understood. This investigation into the most disastrous flood ever known in the Passaic Valley is of timely interest to all classes of citizens dwelling on lowlands subject to floods".

The report proved useful, and the same policy has guided the Geological Survey through a succession of flood reports incorporating new and improved techniques. As flood damage increased, information proved the key to changing public policy to cope with the hazard.

The first role of information was to provide the historic flood magnitude and frequency records that enable engineers to plan and design structural flood control works - dikes, reservoirs and channels. The second role was to define the extent of flood-prone lands. For example, the Passaic report included a Geological Survey topographic map on which flooded areas were delineated.

The importance of recording flood stages and flows has been recognized from early times. Despite the crude equipment available, flood discharges were measured. Advances in design of equipment, development of new measuring techniques and improvement in transportation since 1888 have greatly increased the extent and accuracy of flood records.

The data are important in flood protection and flood insurance efforts. The current network includes about 7,700 active gauging stations, and some kind of flood record is available at many other locations. Regardless of where the next flood may occur, there are likely to be records for one or more floods for the vicinity.

As the lengths of the records of the rapidly expanding gauging-station network increased, early engineering statistics analysed the records with even greater effectiveness. By 1913, engineers who were students of statistics introduced the concept of the flood magnitude-frequency relationship (a 50-year flood, for example). Flood-frequency calculations have gradually been improved over the years. By the 1930s a number of civil engineers had developed statistical methods in which flood-frequency relations were implied.

The long flood records provided samples of flood-magnitude variations with time, but equally important for flood protection was the need to know the upper limits of actual flood experience at gauging stations and elsewhere. Information about rare flood events was obtained indirectly after the event by the slope-area method. This technique required careful surveys of high-water marks to obtain maximum cross-sectional areas and slopes, and required experience in the art of selecting roughness co-efficients in natural channels. The first full-scale use of the slope-area method was the Arkansas River flood of 1921. Today experienced hydraulic engineers can make such flow calculations within about 15 per cent accuracy.

Beginnings of flood-plain management

Flood records and increasing damage showed that structural measures alone could not cope with the flood problem. Flood damages proved too pervasive. There are about five million km of streams in the United States, and about five per cent of the land area is prone to flooding. During the 1950s, research in which Geological Survey engineers were active showed that a new attack on flood problems was necessary.

This new approach centred on adapting the use of flood-prone lands to the flood hazard. Its success depended on ensuring that owners, municipal authorities, bankers and others involved in land management were aware of the flood hazard. Flood plain regulations became "non-structural" alternatives to flood control works. "Flood Plain" became part of the city engineer's vocabulary, and "flood-plain regulations" the conventional wisdom.

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* By Messrs. George W. Edelen, Jr., Hydrologist, George E. Ferguson, Hydrologist and Walter B. Langbein, Hydraulic Engineer, all with United States Geological Survey, Reston, Virginia. Reprinted from American Society of Civil Engineers (ASCE), *Civil Engineering*, vol. 49, No. 2 (February 1979), pp 89-91, with permission.

Part of the "non-structural" approach was flood insurance. Its role was to apply economic discipline to flood-plain use. The insurance policy would be a signal to the otherwise unknowing developer, and the annual premium was a recurring reminder of the hazards and their costs.

These new "non-structural" alternatives created a considerable demand for engineering information for identifying and mapping flood-prone lands with respect to flood frequency for determining flood-risk premiums. At first there was concern about the adequacy of techniques for the new programme.

In 1952 a study by consulting engineers indicated the feasibility of determining the flood risk on the basis of hydrologic experience, but insurance executives believed the extent of liability involved in flood insurance was too great to be borne by the private sector.

A year later Geological Survey engineers also reported that streamflow records were adequate and hydrologic techniques sufficiently well developed for a sound analysis of flood insurance risks. The data also showed that the year-to-year variation in the number and size of floods would require a larger reserve than is necessary in other types of insurance.

With the passing of the Federal Flood Insurance Act of 1956 (PL 1016), Congress recognized that the private insurance industry was not likely to provide flood insurance without federal backing. This Act was the formal beginning of the present national flood insurance programme now administered by the Department of Housing and Urban Development.

Flood-hazard maps

In 1959 the Geological Survey began publishing certain of its flood investigations in a new format which utilized a large-scale map to show inundated areas in greater detail and which relied less on descriptive text. These atlases were also designed to make the insurance industry aware of the variation of risk in overflow areas. The first such atlas was that for the 1951 Kansas River flood at Topeka. Insurance officials remained hesitant, however, about venturing into the flood-insurance field. One of their concerns was the method of calculating actuarial rates in different parts of the flood plain.

The 1961 flood atlas for Boulder, Colorado, offered insurance officials a new product. This was the first time that the inundation boundaries of 25-year, 50-year and 100-year floods had been shown. (see figure I). Due concern was shown by the Geological Survey in taking such a step. Real estate values might well be affected by such inundation maps, and the hydrologic techniques were still being developed. Boulder County officials who co-operated in the atlas' preparation apparently were not disturbed. No adverse public reaction developed, and the insurance programme gained a tool that could assist in actuarial rate claculations.

Since the 1961 Boulder study, the Survey has prepared about two hundred flood atlases. Although they vary in detail of coverage, they hold generally to the Boulder format. A few delineate floods of specific recurrence intervals. Because of the cost, flood atlases were generally issued only for major floods of national interest. The 2,000 copies usually printed are placed on sale to the public. Atlases have been used in formulation of flood-plain regulations and in some cases have been incorporated directly in flood-zoning ordinances.

In 1966, USGS participated in a national task force study of the increasing trend in flood losses (despite substantial flood-control efforts) and considered approaches to reverse the trend. Its recommendations included increasing basic knowledge about the flood hazard and making studies aimed at a practical national flood insurance programme. In sending the task force report to the House of Representatives, President Johnson emphasized that, although more than $US7 billion had been invested in flood control projects in the previous three decades, the current annual expenditures continued at more than $US1 billion. The report was published as House Document 465 dated 10 August 1966.

HD 465 encouraged the Geological Survey in its flood investigations. It recognized the need for determinations of flood frequency or average interval of flood recurrence (as first publicly expressed in the Boulder, Colorado report) as one of the prerequisites for setting premium rates for flood insurance. It also urged that the techniques used by federal agencies in flood frequency computations be standardized - a step that has proven difficult.

More specifically, HD 465 assigned to the Geological Survey the primary responsibility for delineating occasionally flooded areas in the United States. In response to HD 465 and to the National Flood Insurance Act of 1968 (PL 90-448), the Geological Survey has published nearly 13,000 flood-hazard maps since 1969. These maps (see figure II) cover most communities with known flood problems and developing areas with potential flood problems.

Though PL 90-448, Congress expressed its increased interest in flood insurance and presented detailed guidelines. Of particular interest to the civil engineering profession was the authorization for continuing studies needed in the orderly application of insurance for structures located on flood plains.

Through the Flood Disaster Protection Act of 1973 (PL 93-234), which increased flood insurance coverage limits, Congress provided for speedier definition of risk zones within flood-prone areas so that the degree of hazard within each zone could be known at the earliest possible date. The Act specified that several federal agencies, including the Geological Survey, give this matter "highest practical priority in the allocation of manpower". As a condition of federal financial

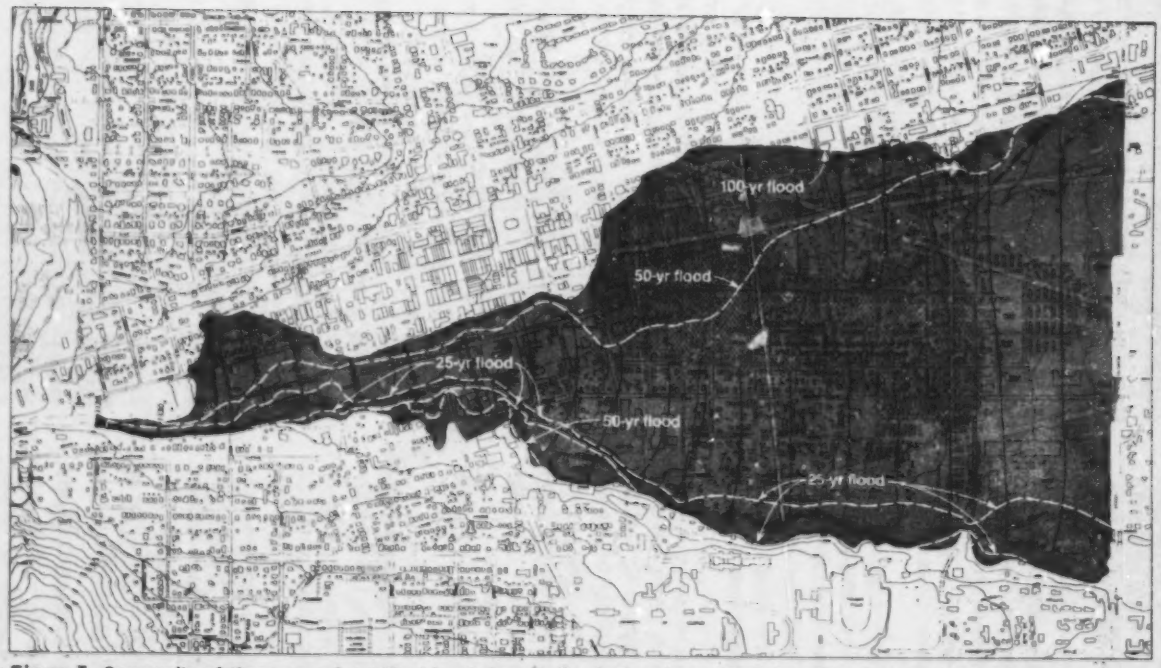

Figure 1. Composite of three maps from Boulder, Colorado, flood atlas shows areas inundated by hypothetical 25-, 50- and 100-year floods and shows contours of 100-year flood water surface. (Area for 100-year flood is shaded, those for 25- and 50-year floods outlined by dashed white lines.) Because inundation area is superimposed on topographic map, depth of flooding at specific locations can be estimated by subtracting ground elevations (shown as light contour lines on original atlas but difficult to see here) from water-surface elevations shown by heavy black contours. Hatched areas show where water would be 0-2 ft deep during 100-year flood.

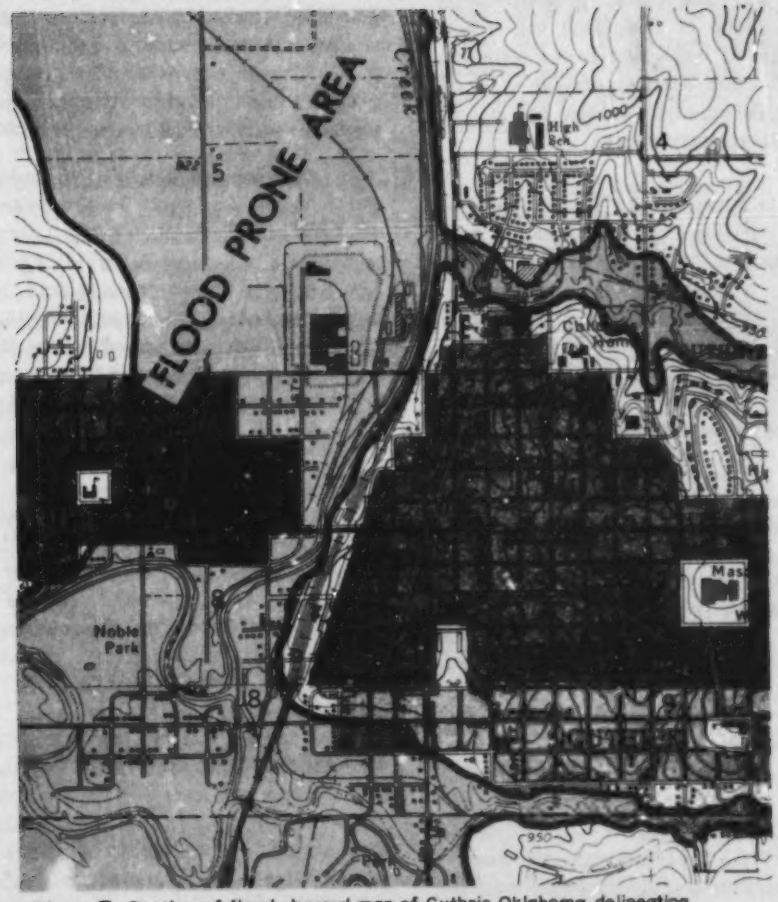

Figure II. Portion of flood-hazard map of Guthrie, Oklahoma, delineating approximate area inundated during hypothetical 100-year flood. Flood-prone areas are identified by past flood records, rather than by detailed field surveys and inspections. Flood-hazard map does not include flood-surface contours or other features of more comprehensive flood atlases illustrated in figure I.

assistance, the States and local communities were required to participate in and to adopt and endorse adequate flood-plain ordinances to reduce or avoid future flood losses.

In July 1976, the Water Resources Council, an independent executive agency of the United States Government, released its plan for "A unified national programme for flood-plain management". The Council recognized that a successful programme would require the participation of all levels of government. Specific recommendations included measures for better co-ordination of federal activities, periodic progress reports to the public, acceleration of flood-plain and hazard studies, standardization of techniques in the collection and analysis of hydrologic data, enactment of flood plain management legislation where needed, and support of state, regional and local governments.

The Council reported that "During the past decade, flood data and flood plain information have been gathered and analysed at an ever-increasing rate, especially through ongoing Federal programmes. However, of the 22,000 communities with flood hazards, less that 25 per cent to date have been furnished detailed flood and flood-related information ... potential users are not always aware of all the information that is available or where to find it."

For example, in addition to the hydrologic work of USGS, the Soil Conservation Service (SCS) has soil maps and interpretations useful for preliminary flood plain management planning throughout about 60 per cent of the country. Furthermore, the Corps of Engineers, the Tennessee Valley Authority and SCS provide technical planning and guidance services through their flood plain management services programmes and make flood insurance studies for the Department of Housing and Urban Development.

The Geological Survey has in recent years put considerable effort into producing flood-hazard maps. Continued research is directed toward improving and refining the techniques of determining the 100-year flood. With the advent of digital computers capable of analysing large quantities of data, new techniques for predicting water-surface profiles are under investigation.

The concept design of an airborne instrument system capable of continuously locating, at the speed of flight and to the required precision, points on the ground was completed under USGS contract in 1976. The prototype system is being built, but the airborne instrument system will not be available for a few years. The new instrumentation will ensure that in the future data for flood investigation will be gathered at a substantial savings in manpower and cost, compared to current methods.

RESEARCH AND DEVELOPMENT*

A cheap, simple rainfall monitoring instrument has been developed by the United Kingdom's Institute of Hydrology. The rain gauge, including all electronics and a liquid-crystal readout, is moulded into a block of clear plastic with only two pairs of terminals as outside links. These connect to a battery and a "tipping bucket" mechanism that collects rain. Three months of daily rainfall figures can be stored in the device's solid state memory which can be extracted with a magnetic probe that triggers switches within the plastic block. Each component of the three-part memory stores up to 240 pieces of information such as daily or hourly rainfall totals. A prototype is being tested in Wales and 10 more are nearing completion for use in the Libyan Arab Jamahiriya, Kenya and the United Kingdom. The cost of each unit is under $US300, compared to the $600 cost for a conventional "tipping bucket" gauge, made from machined brass and excluding the electronics. The sealed electronic units, costing about $100, can be discarded if they fail. The basic rain-gauge design can be easily adapted to monitor temperature, river flows or other quantities.

The power output of conventional hydroelectric plants could be greatly increased by exploiting the heat energy as well as the gravitational energy stored in the reservoir's water. "Vast quantities of absorbed solar energy are stored in the form of freshwater thermoclines behind electric dams," report J.L. McNichols, W.S. Ginell of the McDonnell Douglas Astronautics Company and J.S. Cory of Cory Laboratories, California, in a recent issue of the journal *Science*. Heat engines adapted to hydroelectric facilities with appreciable thermoclines, the scientists suggest, can "increase substantially the output power of such plants." In large reservoirs, "the portion of the head that can be realized by the use of real thermal energy conversion systems, exceeds the hydropotential for the water in most hydroelectric facilities," sometimes by as much as four times. "The thermocline application of hydroelectric facilities for heat engines is particularly appealing because power conditioning and transmission equipment are already installed at such sites," the scientists write.

The low temperature systems that might prove feasible for the thermocline operation, the authors suggest, are the vapour-liquid phase Rankine cycle heat engine under construction for the Ocean Thermal Energy Conversion power plants and the solid state Nitonol heat engine which, "although in a primitive state of development, shows great technical and economic promise."

Combined use of the heat and gravity potential of existing reservoirs could greatly increase the 220.4 million megawatt hours (1977 figures) of hydroelectric power produced at existing dams in the United States at relatively little cost and less lead time than required for construction of new coal or nuclear plants. In addition, "there should be no negative environmental factors associated with power production by this application of heat engines to the thermocline energy resource," they conclude.

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The world's forests are being depleted at an alarming rate, creating potentially dire economic and environmental problems, according to a new study. "Rising wood prices are contributing to inflation in rich and poor countries alike, while land denudation in less developed nations is reducing the capacity of the environment to support human life," said Eric Eckholm in a study for the Worldwatch Institute.

Deforestation, he writes in "Planting for the future: forestry for human needs," is accelerating erosion of crop lands and siltation of streams and rivers, causing deserts to expand and flooding problems to worsen. In addition, crop yields are being reduced. Principal causes of the loss of forest lands are the spread of agriculture, the collection of firewood for cooking fuel and short-sighted harvesting practices.

Forest areas in North America appear stable, but wooded areas in Africa, Asia and Latin America are declining by at least 11 million ha annually.

Dry land suffocates hurricanes, depriving the storms of their energy source. Using a numerical model of a tropical cyclone, researchers Robert Tuleya and Yoshio Kurihara of the National Oceanic and Atmos-

* Excerpts from *Water Newsletter*, published by the Water Information Center, 7 High Street, Huntington, N.Y. 11743.

pheric Administration's Geophysical Fluid Dynamics Laboratory found that the severe storms dissipated because warm ocean water which fueled them was cut off over dry land.

Simulation models using rough land dryer than the ocean, rough land area as wet as the ocean, and land area as smooth as the ocean but with no evaporation indicates that dry, rough terrain decreased storm intensity most rapidly. When oceanic evaporation rates over land were continued and only the roughness of the land was increased, the force of the modelled storm actually intensified. The modelling experiments led researchers to conclude that eliminating the source of moisture was "the single most important" factor leading to the decay of a tropical cyclone over land.

SELECTIVE INFORMATION SECTION*

* Most of the abstracts reproduced below are from the Selected Water Resources Abstracts of the Water Resources Scientific Information Center, Office of Water Research and Technology, United States Department of the Interior, for which acknowledgement is hereby gratefully recorded.

Subject	*Source*	*Description*
Conservation in agriculture	D.W. DeBoer, "Efficient utilization of irrigation water and equipment. Part I: Drip and sprinkler irrigation of carrots and onions. Part II: Analysis of multiple pivot irrigation on a droughty soil", National Technical Information Service, Springfield, VA 22161 (PB-280 501, 1977).	Results from a two-year drip and spinkler irrigation study on carrots and onions are reported. The experimental field site was near Brookings, South Dakota on a 45 cm deep Fordville loam soil; one sprinkler and three drip treatments were investigated in the study. For the first year approximately equal gross amounts of irrigation water were supplied to all experimental plots. The carrot and onion sprinkler yields were smaller than the drip yields. Average carrot and onion yields were approximately 105,000 kg/ha and 60,000 kg/ha, respectively. The water management programme for the second year resulted in overirrigation on the sprinkler treatment and adequate irrigation on the drip treatment. While crop yields were similar, the drip produce was larger on the average than sprinkler produce, and tended to have fewer culls and splits. A field plot study was conducted to simulate the use of one centre pivot irrigation machine on one and/or two adjacent fields. The soil in the experimental area had a depth of 46 cm and an available moisture storage of 6.1 cm. Corn and alfalfa were the experimental crops. Corn yields were significantly reduced when one irrigation machine was used to irrigate two fields of corn instead of one field; however, alfalfa yields were not reduced. Corn yield, for the situation where the irrigation machine is first used on an alfalfa field and then moved to the corn field in early July, was equal to single field corn yield. The alfalfa yield for the July move situation was more than the dryland yield but less than the full season irrigation yield. An economic feasibility study indicated that one irrigation machine on one field of corn or on two fields of alfalfa was most economical when corn or alfalfa were exclusively grown. When combination of corn and alfalfa were considered, commodity prices were a dominant factor.
Conservation in industry	J.A. McNeese, and D.B. Wilson, "Utilization of brackish water in coal gasification", Natural Technical Information Service, Springfield, VA 22161 (B-280 146, 1976).	When coal is utilized for production of synthetic natural gas, approximately 11,000 acre-feet a year will be required for the daily production of 300 million cubic feet (STP) of gas. A major advance would occur in gasification development if part of the required water could be supplied from brackish water sources. The main consideration in the use of brackish water as process water is the deposition of the salts from the brackish water. Three salt systems supplied from a synthetic saline solution were analysed for salt deposition during the gasification of a coal-salt solution paste. The salts studied were sodium chloride, potassium chloride, and sodium sulfate. The study examined the leachability of these salts from the product coal-ash; most of the salts introduced into the reactor system were leachable either from the product mixture or from the reaction vessel. The salt material balance could be closed by accounting for salts carried from the system either as mist or as particulate. While not a definite deterrent to the use of brackish water in an *in situ* gasification process, the leaching of these salts into ground-water and subsequent deterioration of the ground-water

Subject	*Source*	*Description*
		aquifer would have to be considered. In the case of the Lurgi reactor system, brackish water could not be used until corrosion considerations had been examined. Conclusions were: common brackish water salts are leachable from the spent reaction zone products in a packed bed gasification reactor; ash fusion may occur at temperatures well below expected high silica and fusion points; potential damage to aquifers could result from salt migration from a spent *in situ* reaction bed; in a packed bed reactor salts tend to migrate out the bed interior to the reactor wall.
Conservation in industry	E.E. Whitlatch, Jr., "Coal gasification and water resources development", *Journal of the Water Resources Planning and Management Division,* Proceedings of the American Society of Civil Engineers, vol. 103, No. WR 2, pp. 299-314, November 1977.	A method is developed for determining the location of high and low-STU coal gasification facilities to minimize the cost of plants, gas transmission, coal supply and transport, solid waste disposal and water supply. Economic efficiency is achieved in meeting the demand for gas at designated market centres. Linear programming optimization models are developed for this purpose. The method should be useful in planning the joint development of energy and water resources in those regions designated by the Water Resources Council as being constrained by water availability in achieving national energy self-sufficiency. The models can also be used to indicate the trade-offs between environmental concerns and economic efficiency. It is concluded that the relative availability of water at a potential coal gasification plant site may significantly affect the final price of gas. It is recommended that detailed studies of water use and conservation in both the Lurgi and advanced technology processes be undertaken.
Control of water on the surface	M. Ball, W.F. Bialas, and D.P. Loucks, "Structural flood control planning", *Water Resources Research,* vol. 14, No. 1, pp. 62-66, February 1978.	Flood routing methods, together with a branch and bound backtracking optimization routine, are used to evaluate alternative capacities and locations of various flood control structures required to protect a floodplain from a specified design flood. Described is this preliminary planning procedure, and its use for estimating least-cost combinations of flood storage capacities in reservoirs, temporary flood storage basin capacities, levee locations and heights, and increased channel capacities in river basin systems is illustrated. A prime consideration in the development of this method was computational efficiency; it can be altered to estimate the structural flood control plan that maximizes expected annual damage reduction benefits less the total annual cost of flood protection. The model can be extended to include a distribution of floods rather than a single design flood.
Control of water on the surface	W. Whipple, Jr., "Flood management for small urban streams", *Journal of the Water Resources Planning and Management Division,* Proceedings of the American Society of Civil Engineers, vol. 103, No. WR 2, pp. 315-324, November 1977.	Experiences in Princeton, New Jersey are used to analyse flood problems of small urban streams, including building in flood plains, increased floods due to urbanization, and accentuated erosion tendencies. A detailed survey and flood analysis were very beneficial, followed by flood plain zoning and a requirement for flood detention storage by developers. Culverts now too small to handle increased floods constitute a defense against erosion

Subject	*Source*	*Description*
		also caused by the floods. Reconsideration of criteria for culvert design in such situations would be valuable. Federal programmes fall short of meeting the rather complex problems in small urbanizing watersheds.
Control of water on the surface	R. Charudattan, B.D. Perkins and R.C. Littell, "Effects of fungi and bacteria on the decline on arthropod-damaged water hyacinth", *Weed Science*, vol. 26, pp. 100-107, March 1978.	A survey of the fungal and bacterial flora of water-hyacinth infested with Neochetina eichhorniae (weevil) and Orthogalumna terebrantis (mite) was undertaken to determine the role of micro-organisms in the decline of this host in Florida. Generally arthropod-infested plants were more diseased, had smaller laminae, lower numbers of live petioles and higher numbers of dead petioles per plant than non-infested plants. Several parasitic fungi and soft-rot bacteria occurred in higher numbers on arthropod-infested than on non-infested plants. Acremonium zonatum, a virulent pathogen of water hyacinth and other necrotic leaf-spot diseases ('disease B'), were predominant on arthropod-damaged plants. Disease B was independent on the arthropods, while A. zonatum incidence on water hyacinth was related especially to demand by adult mites. The weevil also aided A. Zonatum infections by creating ports for its entry into the host. In laboratory, water hyacinths could be killed by the combined effects of the weevil and A. zonatum. In fields, the combined effects of arthropods and diseases led to reduction in the photo-synthetic area of water hyacinth and to root-and crown-rots. It is recommended that biological control of water hyacinth in Florida should include pathogens and insects.
Control of water on the surface	M.K. Garrett and V. Carter, "Contribution of remote sensing to habitat evaluation and management in a highly altered ecosystem", *Transactions of the 42nd North American Wildlife and Natural Resources Conference*, 1977. Published by the Wildlife Management Institute, Washington, D.C., 1977.	The Great Dismal Swamp National Wildlife Refuge, established in 1973, currently encompasses 21,500 ha of forested wetland within the Great Dismal Swamp of south-eastern Virginia and north-eastern North Carolina. Approximately 50,000 ha of the total 85,000 ha of swamp have been recommended for public ownership; the remaining acreage has been separated from the main body of the swamp and has been extensively ditched in preparation for agriculture. The United States Fish and Wildlife Service has the responsibility for evaluating and developing management priorities for the primary 50,000 ha unit. The refuge service co-operates with other Federal, State and city agencies and provides educational opportunities for the general public. The purpose of this paper is: (1) to explain why the Great Dismal Swamp is considered a highly altered ecosystem; (2) to illustrate how the formulation of management policy is complicated by the habitat diversity resulting from physical alterations; and (3) to demonstrate how remote sensing has aided in both habitat evaluation and management of the swamp ecosystem.
Control of water on the surface	N.I. Maslov, "Regional working formula of maximum runoff in the Syrian Arab Republic", *Soviet Hydrology*, vol. 15, No. 2, pp. 102-105, 1976.	The Syrian Arab Republic has an area of 185,000 sq km. In the west it borders on the Mediterranean Sea and changes to the Syrian Desert in the east. Most of the country is a plateau, ranging in elevation from 200 to 700 m above sea level, almost void of vegetation. At the

Subject	*Source*	*Description*
		present time, there are sufficient data on precipitation, obtained by the Meteorological Service of the SAR, and field observations of surface runoff, performed by Soviet specialists, to develop a sounder unified method for computing maximum runoff with allowance for regional conditions. There are 234 active meteorological stations in the country with precipitation observation records from 10 to 43 years. The purpose of this investigation was to establish from questionnaires the maximum flood stages, estimate their empirical probability of being exceeded, and then to compute the maximum discharges from morphometric cross sections and longitudinal channel profiles taken in the field. It was concluded that the parameters of heavy precipitation in regions with a poorly developed precipitation station network could be refined on the basis of data on daily precipitation maxima and monthly precipitation totals. The network of meteorological stations that record these data is denser, as a rule, and the observation period is much longer. It is also necessary to analyse available pluviograph records for shorter time intervals. This will increase the reliability of hydrologic computations considerably.
Control of water on the surface	L.A. Heindl, "Review of Australia's water resources 1975", American Geophysics Union *EOS,* vol. 59, No. 1 January 1978.	A condensed assessment is presented of the publication *Review of Australia's Water Resources 1975,* its first since the initial assessment attempt in 1963. In the intervening years the Australian and State Governments expanded their programmes of water data collection, field investigation and hydrological research, and broadened their approach to water management to include consideration of socio-economic and environmental factors. Under these circumstances it was logical to expect a 1975 review of Australia's water resources to include evaluations of the immeasurable factors and an assessment that would attempt to balance the immeasurable and the measurable. In spite of some excellent pictures and descriptions, the volume is predominantly a straightforward summary of discharges per time per unit area.
Data acquisition	A.T. Joyce and R.H. Griffin, II, "The use of Landsat digital data and computer-implemented techniques for an agricultural application", National Technical Information Service, Springfield, VA 22161 (NASA RP 1016, 1978).	Agricultural application of a resource inventory system that combines Landsat-acquired data and soils information is described. The system was developed to aid country agents in routine work, to assess over-all agricultural potential of a region, and to estimate upcoming harvest for major crops. The demonstration area was Washington Country, Mississippi. The data processing flow involves: installing and operating the image display device; performing classification of Landsat raw data; performing rectification of information; mapmaking; applying the information (for acreage compilation, change detection, spatial analysis, and theme inventory); building the data base; digitizing other information (on soils, slope, elevation, rainfall, and accessibility); and making applications of the data base and materials to estimate crop production, assess wildlife habitat, inventory reforestation needs, and

Subject	*Source*	*Description*
		select sites for various projects. The results of the application are shown in production estimates for cotton and soybeans in the areas surveyed. Examples of output products in both line printer and map formats are included, and product adequacy assessment is made. The appendices contain data forms, coding diagram and density plots, and computer requirements.
Data acquisition	J.E. Colwell, D.S. Gilmer, E.A. Work, Jr., D.L. Rebel and N.E.G. Roller, *Use of Landsat data to assess waterfowl habitat quality*, Ann Arbor, Environmental Research Institute of Michigan, January 1978.	The feasibility of using Landsat data is examined for (1) the analysis of annual waterfowl production by monitoring the number of breeding and brood ponds that are present, and (2) the ability to assess waterfowl habitat based on various relationships between ponds and surrounding upland terrain types. A large coarse Landsat census can improve the estimate of the number of ponds in a population with respect to an accurate small sample done by low-flying aircraft. One reason is the large semi-random variability in pond area per small sample unit. In a multitemporal Landsat classification map, marsh categories were reasonably well recognized although there was some misclassification between shallow and deep marsh. Bare soil was generally well recognized, as were the other upland terrain classes. Landsat data may also determine waterfowl habitat quality, as related to pond and terrain conditions. A discussion of Landsat determination of pond area is included in an appendix. Some effects of size and shape are also indicated.
Data acquisition	K.S. Long and L.E. Link, Jr., "Remote Sensing of Aquatic plants", *Proceedings of the Eleventh International Symposium on the Remote Sensing of the Environment*, Vicksburg, MS, 25-29 April 1977.	This is a synopsis of the work being accomplished by the Army Corps of Engineers' Aquatic Plant Control Research Programme on the remote sensing of aquatic plants. Initial study efforts have been to determine the feasibility of acquiring information concerning the extent and composition of aquatic plant assemblages by using currently available remote sensing procedures. Included are a literature review to identify current sensing work by other investigators and a discussion on future study efforts to be done in this field. Results to date have indicated that the sensor types best suited for assessment of aquatic environments are colour, colour infrared, and black-and-white infrared film, which furnish consistently high contrasts between aquatic plants and their surroundings.
Ecological impact of water development	D.I. Hellstrom, "A methodology for preparing environmental assessments", National Technical Information Service, Springfield, VA 22161 (No. ADA-040 113, November 1976), 34 p.	This technical report is prepared as a guide for the preparation of environmental assessments. To be used by Air Force field personnel, the report presents methodologies to be used in assaying important environmental impacts resulting from operations, construction and other actions. Reviewed are the environmental assessment process and relevant federal environmental laws and regulations. The report then discusses the nexus between environmental considerations and planning; presents an inventory procedure; recommends an evaluation methodology, outlines various ways of assessing impacts; and ends with recommendations for data collection referencing and the establishment of an environmental data bank.

Subject	*Source*	*Description*
Ecological impact of water development	K.M. Duke, N. Dee, D.C. Fahringer, B.G. Maiden and C.W. Moody "Environmental Quality assessment in multiobjective planning." Denver, Bureau of Reclamation, Final Report, November 1977, 148 p.	A methodology for environmental quality assessments is described which has been developed to implement the Principles and Standards developed by the Water Resources Council and Bureau of Reclamation Planning guidelines. A four-level heirarchical structure for environmental quality account is described with 4 components, 15 categories and 75 evaluation factors used to organize environmental measurements into a standard procedure for displaying the beneficial and adverse effects to water resource development projects on environmental aquality. Examples of appropriate measurements for each evaluation category are provided, along with suggested tables that might be used to display and summarize data used in the evaluation. The report also compares a number of other methodologies with the principles and standards previously developed by Bureau of Reclamation guidelines.
Ecological impact of water development	"Operation of the national wildlife refuge system (final environmental statement)", *Fish and Wildlife Service*, Washington, D.C., November 1976., 697 p.	Continued operation of the National Wildlife Refuge system is examined from approximately the FY 1974 level of activity projected to 1985. Annual funding requirements are estimated at $US22 million, with 883 permanent personnel. Increased costs resulting from inflation and establishment of new refuge areas are anticipated. A description of the Programme activity includes a statement of purpose and action, the Refuge mission objectives, current programme output and cost assessment, action to implement the programme (wildlife population, land, and people management, refuge functions, and land acquisition and disposition), Fish and Wildlife Service Programme management, budgeting and funding, and interrelationships with other projects. Environment is discussed in terms of historical perspective; physical and biological resources; classification of refuge types; cultural, social, and economic environment; and probable future environments (without the National Wildlife Refuge System). Environmental impacts and mitigative measures are assessed for: (1) biological and physical environment; (2) wildlife and non-wildlife recreation; (3) visitor safety; and (4) cultural and economic conditions. The impact on topography and natural features and the relationship between short-term uses and long-term productivity are assessed. Alternatives to the current Programme are analysed and cost-assessed. Appendices address such topics as revenue sharing, programme planning system policies, research, and current and projected programme activity.
Ecological impact of water development	"Physical management of coastal flood plains: Guidelines for hazards and ecosystems management", Task One Report, Prepared for the Council on Environmental Quality, Washington, D.C., December 1977, 179 p.	Focusing primarily on water systems and water-related aspects of the shoreline, development and conservation guidelines are developed for nine generalized "places of concern". All nine are distinguishable natural features of the coastal zone: (1) coastal watersheds; (2) shoreland water systems; (3) coastal floodlands; (4) saltwater wetlands; (5) bluffs, (6) dunes; (7) beaches; (8) basin floors; and (9) coastal waters. In each subsection are discussed, in sequence: characteristics and boundaries, ecological functions, and conservation guidelines and

Subject	*Source*	*Description*
		restoration techniques. The subsections are illustrated with examples that augment the text or illustrate special technical issues or processes.
Estuaries	A.V. Rao and D.J. Mehta, "Desalination techniques for conversion of brackish water into potable water for small communities", *Desertification and Its Control*, New Delhi, Indian Council of Agricultural Research, 1977.	Various techniques for supplying potable water to small communities in India that presently have saline or brackish water are presented. Three desalination techniques developed by the Central Salt and Marine Chemicals Research Institute are discussed: (1) use of solar stills, (2) reverse osmosis, and (3) electrodialysis. Solar stills are ideal for small isolated communities where the water requirement is low, the needed power is not available, and the water is saline. Solar stills are simple to construct and the operating and maintenance costs are small. The operation of a solar still is briefly explained. Reverse osmosis employs semi-permeable non-ionic membranes for the purification of water. Its advantages are presented. Electrodialysis employs perm selective membranes for the desalination of brackish water. Its operating procedure and advantages are discussed. The estimated capital costs and the operating costs for plants of 5,000 litre-per-day capacity of solar stills and 10,000 litre-per-day of the other two types are presented.
Evaluation process	Harold E. Albert (ed.), "Education of water resources planners and managers for effective public participation", National Technical Information Service, Springfield, VA, 22161 (PB-280-243, February 1978).	Water resources development should provide measures and facilities which are responsive to the long-run needs and evolving preferences of the public. An important means of achieving this goal is effective participation in water resources planning and management. In order to achieve this, key representatives of the diverse interest groups and of the public must be sufficiently familiar with both the obvious and the subtle dimensions of public participation, and must be aware of objectives as well as alternative approaches to the process. Participants at this symposium included representatives from federal, state, and local government agencies, and from private interest groups. The conclusions reached by this panel were: (1) the public must be divided into publics and having the right publics involved in the planning stage is crucial to the development stage; (2) the right publics must be involved as early as the pre-planning stage, although all of the publics who eventually will be involved need not be so at the same time; (3) there are a variety of techniques for public involvement and no single technique is adequate for all projects. A case study was analysed by leading participants from both the public and private sector, and this substantiated the accuracy of the above conclusions. In addition to the symposium, an extensive bibliography was compiled and annotated, and is included.
Evaluation process	"A guide to environmental benefits assessment in economic impact studies", Illinois Institute for Environmental Quality, HEQ Document No. 77/32, October 1977.	Environmental benefits of pollution control are considered. Two audiences are addressed: (1) those generally interested and/or involved in the benefits assessment process, but with little or no technical background and (2) those involved in the preparation and evaluation of economic impact studies. A systematic organizing

Subject	*Source*	*Description*
		framework for benefits assessment was developed. Chapters summarize key aspects of each major stage in the process. Detailed technical material is provided in the appendices.
Evaluation process	Army Corps of Engineers, "Evaluation of planning for fish and wildlife: John Redmond reservoir project", National Technical Information Service, Springfield VA 22161 (AD-A034 136, June 1976).	This study's purpose was to compare the original projections of activities associated with fish and wildlife with the actual activities. The study area involves the John Redmond Reservoir and surrounding lands in Lyon and Coffey Counties, Kansas. The total project area is 12,829 ha and the Reservoir itself is 3,804 ha. Post-impoundment surveys indicate that the project annually supports waterfowl hunting in excess of the prediction by 300 per cent and upland game hunting 400 per cent in excess of the prediction. Use of the project by migratory waterfowl was as expected for ducks, but was only 20 per cent of the expected level for geese. The qualitative fisheries predictions were generally accurate. The predicted volume of angling was about 38 per cent higher than the actual angler presure of 1974. The post-impoundment angling use in the Grand (Neosho) River below the Reservoir was four times the predicted value. The project evaluation prepared by the Fish and Wildlife Service (FWS) in 1961 was perfunctory. Reports prepared in 1963 by FWS to justify authorization of the national wildlife refuge on the reservoir land were more comprehensive.
Evaluation process	R.B. Ditton, D.J. Schmidly, W.J. Boeer and A.R. Graefe, "A survey and analysis of recreational and livestock impact on the riparian zone of the Rio Grande in Big Bend National Park", *Proceedings: River Recreattion Management and Research Symposium*, January 1977, Minneapolis, Minnesota, USDA Forest Service General Technical Report NC-28, Department of Agriculture, St. Paul, Minn, p. 256-266, 1977.	The Rio Grande River of the Big Bend National Park (Texas) has experienced dramatic increases in recreational and water use. The National Park Service has thus found it necessary to secure information concerning the actual and potential impact on the river and on associated land area ecosystems from present levels of human usage. Visitor usage patterns, biological conditions, and selected parameters of recreational impact (including litter, trampling, tree cutting, and human waste) were measured over a 12-month period. Use and impact were shown to be strongly and positively correlated. However, recreational impact was not significantly related to biological health of the area. Cluster analysis was used to group areas into three categories based on degree of impact; only one of every four sites was indicated as heavily impacted. Principal components analysis identified human impact parameters as best discriminators between sites.
Evaluation process	W.L. Griffin and B.R. Beattie, "Economic impact of Mexico's 200-mile offshore fishing zone on the United States Gulf of Mexico shrimp fishery", *Land Economics*, vol. 54, No. 1, February 1978.	Explored is the expected economic impact of Mexico's 200-mile extended jurisdiction limit on the United States shrimp fleet in the Gulf of Mexico. Specifically, the average annnual reduction in shrimp landings from Mexican waters by the United States fleet is estimated, and an assessment is made of the consequent expected increase in effort that will be exerted off the United States coast. Finally, the impact of this shift in effort is explored in terms of rent loss to the fishery and break-even product prices required to achieve open-access equilibrium. Given the present shrimp price and cost-of-

Subject	*Source*	*Description*
		production situation, it appears that adjustment to Mexico's 200-mile extended jurisdiction will not result in negative rents for the United States Gulf shrimp fleet.
Evaluation process	R. Vazquez (ed.), "Puerto Rico's water resources problems and research needs", National Technical Information Service, Springfield, VA 22161 (PB-280 100, 1974).	The proceedings of a conference and planning session to identify Puerto Rico's water resources problems and research needs are presented. Panel discussions were conducted on water for agriculture, water for development, water for industry, and on water and environmental quality research and development efforts. The agricultural discussion centred on water resource needs for sugar production and on federal soil and water conservation programmes. Economics, flood control, domestic water use problems and research needs, and Corps of Engineers water resources programmes were discussed with regard to development. Concerning industrial development, water use problems and research needs for industry and water resource planning were treated. The panel on water and environmental quality discussed water quality problems and research needs, Environmental Protection Agency (EPA) water resources programmes, United States Geological Survey (USGS) water resources research, and water resources in the Virgin Islands.
Evaporation and Transpiration	D.G. Jordan and D.W. Fisher, "Relation of bulk precipitation and evapotranspiration to water quality and water resources, St. Thomas, Virgin Islands", Branch of Distribution, United States Geological Service, 1200 S. Eads St., Arlington, VA 22202 (Water Supply Paper 1663-I, 1977).	St. Thomas, Virgin Islands, is composed almost entirely of volcanic rocks mantled by a thin soil seldom more than 60 cm. thick. Rainfall, averaging about 1000 mm annually, has an orographic distribution related to the central ridge of the island, altitude 180 to 450 m, and the easterly to north-easterly trade winds. The mineral content of bulk precipitation falling on the island is derived principally from the sea although soil dust contributes much of the calcium, sodium, and bicarbonate. Two thirds of the sulfate in the precipitation is provided by sea salts: the remainder is derived from other sources. The concentration of the constituents of bulk precipitation fluctuates widely month to month, but the load of the consitutuents shows little monthly variation. Bulk precipitation is concentrated on the land surface and in the soil zone. From there it is carried into the ground water during recharge or is removed by storm-water runoff. It is the principal source of minerals in the waters of the island. Soil-moisture demand and evaporation limits recharge to 25 and 50 mm annually for the greater part of the island. Evapotranspiration also occurs directly from the aquifer. The salts left further increase the mineralization of the ground water. Water loss from the aquifer by evapotranspiration ranges from 40 to 80 per cent of the recharge.
Ground water	P.S. Goel, P.S. Datta, and B.S. Tanwar, "Measurement of vertical recharge to ground water in Haryana State (India) using tritium tracer", *Nordic Hydrology*, vol. 8, No. 4 pp. 211-224,	Downward movement of soil moisture due to rainfall and supplemental irrigation in the unsaturated zone has been followed by tagging a layer of soil with tritiated water at a number of sites in the State of Haryana. The activity apparently moves by a piston type flow. The average recharge for 15 sites during the interval July-

Subject	*Source*	*Description*
	1977.	November 1973, has been equivalent to 9 cm of water which is 14 per cent of the irrigation plus rainfall. For 18 sites sampled after two monsoons (July 1973 to December 1974) the average recharge is 19 cm and the fractional recharge is 0.15. Wide variations in recharge values are noted. The most significant factor affecting the fractional recharge is the clay content of the soil.
Ground water	P.S. Datta, and P.S. Goel, "Ground-water recharge in Punjab State (India) using tritium tracer", *Nordic Hydrology*, vol. 8, No. 4, pp. 225-236, 1977.	Vertical recharge to ground water due to the 1972 monsoon plus supplemental irrigation was measured at 21 sites in the State of Punjab using tritium tracer. Average recharge was found to be equivalent to 8.5 cm of water. This is about 18 per cent of the average rainfall and 12 per cent of the total watering.
Ground-water	D. Huntley, "Ground-water recharge to the aquifers of Northern San Luis valley, Colorado: A remote sensing investigation", National Technical Information Service, Springfield, VA 22161 (E77-10149).	The northern San Luis Basin can be divided into three distinct but hydrologically connected provinces. Faults are important in all regions: providing areas of increased permeability or acting as ground-water barriers. Use of aerial photography and thermal-infrared imagery resulted in a significant savings in time and increase in accuracy in this regional ground-water supply. Reflectance measurements showed that absolute reflectance differences in one part of the spectrum could be extrapolated to the rest of the photographic spectrum. Spectral variations related to vegetation variation, in turn related primarily to water availability, are extremely important in hydrogeologic studies. Both vegetation and saline soils can be used to distinguish between shallow and deep ground-water, but saline soil distribution is a more dependable indicator in San Luis Valley. Temperature differences seen on thermal-infrared imagery can be related to differences in thermal inertia, solar reflectance, evaporation rates, or subsurface temperature distribution. Both evaporative cooling and temperature effects due to varying ground-water depth affect the diurnal temperature curve in the same manner and are indistinguishable.
Ground-water management	H.I. Nightingale and W.C. Bianchi, "Environmental aspects of water spreading for groundwater recharge", United States Department of Agriculture, SEA Information Division, Hyattesville, MD 20782, *Technical Bulletin* No. 1568, October 1977.	Field observation data on the changes in the plant and animal communities during the first five years of operation of the Leaky Acres Recharge Facility in Fresno California are presented. The original arid ecosystem has changed to aquatic with each continuous recharge period of 8 to 10 months each year. The nature and magnitude of ecological changes were recorded as the aquatic environment was generated and stabilized: the impact of these changes on recharge and the surrounding urban area is discussed. Canal water quality parameters, soil chemical and physical properties and geological parameters which are critical to maintaining the facility's infiltration rate of 16-23 cm/day are summarized. After five recharge periods the ecosystem appears fairly stable in relation to the canal water quality plant nutrients and biota. Observations show that for the sandy soils the infiltration rate of the basins can be maintained by: (1) minimizing the amount of aquatic plant growth and resulting deposition of organic

Subject	*Source*	*Description*
		material that can cause biological clogging of the soil: (2) preventing turbid (greater than 20 FTU) canal water from carrying high loads of silt and clay from entering the basins: (3) preventing intrabasin erosion during filling: and (4) minimizing soil disking and compaction. A table of preconstruction surveys was formulated as a guide to generate information needed to write an intelligent and practical environmental impact report for a proposed basin-type recharge facility and to design and operate a recharge facility.
Hydraulics	P.L. Knutson, "Designing for bank erosion control with vegetation". Charleston, SC, Army Coastal Engineering Research Center, Reprint 78-2, 2-4 November 1977.	Marsh plants are effective in stabilizing eroding banks in sheltered coastal areas. Exceptional results have been achieved in a variety of intertidal environments at a fraction of the cost required for comparable structural protection. Techniques are available for the efficient propagation of several marsh plants for use in bank stabilization. This paper provides design criteria for determining site suitability; selecting plant materials and planting methods; and estimating labour requirements on a project-by-project basis.
Hydraulics	"Safety of dams, a review of the programme of the United States Bureau of Reclamation for the safety of existing dams", Washington, D.C., National Academy of Sciences, 1977.	The National Research Council (NRC) Committee on the Safety of Dams made specific recommendations to the Bureau of Reclamation: (1) establish an independent dam safety office, responsible directly to the Commissioner of Reclamation, to discharge the single function of dam and reservoir safety in the public interest; (2) ensure that adequate funds and manpower are provided to accomplish all essential elements of dam safety within established time frames; (3) extend the recently adopted policy to use independent consultants on all future designs for major dams to encompass engineering evaluation for safety of existing dams; (4) provide field instrumentation to monitor the behaviour of dam structures and to assist in evaluating safety for all major dams; (5) locate strong motion seismographs at all major dam sites in earthquake zones 3 and 4; (6) increase the scope of and participation in the examinations under the Review of Maintenance Programme in order to obtain a comprehensive technical assessment of project features; (7) establish a landslide surveillance programme by identifying all significant active, inactive and potential landslides at every reservoir; (8) improve hydrological methodologies such as application of mathematical watershed models, spillway design flood methodology and state-of-the-art methods to develop inundation maps; (9) make a more complete geologic and seismologic analysis for existing dams in order to estimate maximum credible earthquakes in regions of high to moderate seismicity or from active faults; (10) establish a more effective and comprehensive emergency preparedness programme; (11) consider Engineering and Research Center organizational changes to strengthen the role and responsibility of engineering geologists and geotechnical engineers; (12) give consideration to the preparation and implementation of a probabilistic or risk analysis programme for the purpose of ranking

Subject	*Source*	*Description*
		major dams in accordance with the hazard potential and probability of a failure or partial failure of the structure.
Identification of pollutants	R.L. Kaesler, "Diversity of stream communities under conditions of pollutional stress". National Technical Information Service, Springfield, VA 22161 (PB-280 500, 1978).	Indices of species diversity, which are often used to assess the state of the aquatic environment, are single values that combine the number of species in a sample with evenness of their distribution. They are convenient for expressing the state of the environment to non-ecologists, but because of this simplicity they are easily misapplied, leading to erroneous interpretation. The purposes of this research were to find the index of diversity most appropriate for stream surveys; to find, if possible, ranges of diversity indicative of healthy streams, moderate pollution, and heavy pollution; and to develop and test means of reducing the cost of stream surveys by considering taxonomic categories above the species level, such as families and genera, the value of small samples, and non-taxonomic hierarchies. By using Brillouin's index, one may reduce the size of samples collected and, hence, the cost of the field survey and the time needed to collect data in the laboratory. Moreover, some purposes of applied aquatic ecology are served by working with families or genera rather than species, again with appreciable savings of time and money. Sufficient knowledge of functional morphology and trophic structure has accumulated to allow ecologists to base environmental studies on them. One may thus gain better understanding of the structure of an aquatic community than with traditional taxonomic data.
Precipitation	P. Brochet, "The 1976 drought in France: Climatological aspects and consequences (La secheresse 1976 en France: Aspects climatologiques et conséquences)", *Hydrological Sciences Bulletin*, vol. 22, No. 3 p. 393-411, September 1977.	The four classical definitions of drought were mentioned: (1) pluviometric drought, numerically characterized by a pluviometric ratio; (2) climatic drought, depending on the potential water budget; (3) agricultural drought, referring to the easily available soil water storage; and (4) hydrological drought, recognized by an anomaly in the water supply to the water courses. The first two types were analysed with respect to the 1976 drought in France, and the results were plotted on maps. The meteorological causes of the drought were examined, using data from Europe and North Africa. Finally, the effects of the drought on surface water (ground water does not appear to have been affected), river transport, pollution, hydroelectric power supply, and above all on agriculture, were given.
Precipitation	J.A. Mabbutt, "Climatic and ecological aspects of desertification", *Nature and Resources*, vol. 8, No. 2, p. 3-9, April-June 1977.	Desertification is the spread of desert conditions beyond desert margins, or the intensification of desert conditions within them. The problem of increasing desertification is examined and its causes are discussed. The primary focus is upon the climatic and ecological aspects. Questions explored concerning climate and desertification are concerned with man's effect on deterioration of desert climates, the problems of weather forecasting, and the possibility of man changing the desert/climate to his advantage. The value of using an

Subject	*Source*	*Description*
		ecological approach in dealing with the problem of desertification is examined. The physical processes of desertification are discussed.
Stream flow and runoff	A.M. Vladimirov, "Low river runoff", *Soviet Hydrology*, Selected Papers, vol. 15, No. 2, pp. 138-141, 1976.	There are two main phases in the water regime of rivers: a high-flow (spring flood and flash flood) phase, and a low-flow phase. The latter is typical of periods with limited water inflow into rivers and can be observed in winter and the summer-autumn season. In those periods, river runoff is tens and even hundreds of times lower than during the spring flood and flash floods. Runoff in some rivers becomes depleted to the extent that the rivers dry out (in summer) or freeze solid (in winter). The duration of the low-flow period may vary from ten days to 10-11 months, depending on climatic conditions and the size of the river. In that period, various branches of industry may experience a severe water shortage. Furthermore, in some regions the water shortage may be the only factor limiting the development of industry and economy. It is obvious, therefore, that sufficiently accurate information on river runoff during the low-flow period is sorely needed. Correct analysis of the conditions of runoff formation and development of sound recommendations for computations are impossible without a clear idea of the role of physiographic factors in river runoff formation. A combination of factors affects the conditions of formation of low runoff and its magnitude. This combination can be divided into two groups: climatic factors and underlying-surface factors.
Structures	H. Otsuki, Y. Nakamichi, and K. Kawasaki, "A dynamic study of water works piping under earthquake shocks" (in Japanese), *Journal of Japan Water Works Association*, No. 517, October 1977.	The impact of earthquake tremors on various types of underground pipe conduits for water transport was examined within the context of theoretical pipe dynamics. Subsurface conduits extend along the ground surface and are encased in sand and soil. The seismic force of an earthquake acting on basement causes shearing as surface waves move over the superficial base. The resulting ground deformation causes similar deformation and stress in the conduit body. The stress resulting from the seismic force and ground deformation is distributed over various parts of the pipe. The earthquake tremor causes the ground to vibrate, initiating a parallel vibration of the underground conduit. This sympathetic response to the seismic vibration of the ground occurs in all underground conduits.
Ultimate disposal of wastes	"Let them eat sewage down at the fish farm", *New Scientist*, vol. 77, No. 1085, January 1978.	An estimated 1.4 million tons of dried sewage is disposed of each year in England, representing 1 million tons of primary treated effluent and 0.4 million tons secondary treated sewage. Primary effluent contains about 16 per cent available protein; secondary sludge contains about 40 per cent available protein. Sewage sludge is discussed as a possible source of food for the production of fish protein in fish farms. The supplemental feeding of sewage effluent to fish which are raised as a protein source for human consumption was suggested as an energy-and food-conserving measure. As an alternative to the direct feeding of sewage sludge to fish,

Subject	*Source*	*Description*
		it was suggested that feed worms and fly larvae be reared on the solid wastes. A food chain system such as this could produce an estimated 30 tons of fish/50 tons of sewage sludge. Although human consumption of the sewage-fed fish may not be acceptable, the fish could be marketable as fish meal in animal feeds.
Ultimate disposal of wastes	"Proceedings of the Bioconversion Energy Research Conference held at Massachusetts University, Amherst on 25-26 June 1973", National Technical Information Service, Springfield, Va 22161 (PB-231 149, 1973).	Summaries are provided of papers presented at the Bioconversion Energy Research Conference held 25-26 June 1973. The Conference investigated the feasibility and applicability of anaerobic conversion of waste materials to methane gas; technical papers were presented and discussion sessions followed. The articles are entitled: "Methane fermentation - furture promise or relic of the past?; "Terminal anaerobic dissimulations of organic molecules"; "Resource recovery from municipal solid waste"; "Anaerobic processing of organic refuse"; "Dynamic modeling control strategies for the anaerobic digestion process"; "Methane production from the anaerobic treatment of petrochemical industry wastewaters"; "Bioconversion energy studies at the University of California, Berkeley"; "Thermophilic anaerobic digestion of solid waste"; "Conversion of solar energy to fuel gas"; and "Anaerobic fermentation of wastes". A list of conference participants is provided.
Ultimate disposal of wastes	"Seawater plus sewage yields lots of the fuel gas", *Machine Design*, vol. 50 No. 3, February 1978.	A technique for producing hydrogen gas by reacting sea water with molten ferrous iron in subsurface magma has been developed by Sandia Laboratories of Albuquerque, New Mexico. It is estimated that 500 lb/hr of hydrogen gas would be produced by pumping 150,000 lb/hr of water into basaltic magma at a temperature of 1,200 C. Hydrogen production in magma containing 2-12 per cent ferrous iron can be increased by the addition of biomass to the water. Suggested sources of biomass are sewage sludge, waste by-products from crop havesting and processing, and seaweed. The cellulose of the plants releases its hydrogen during the reaction with the magma. The reaction of water containing 10 per cent biomass with magma at 1,300C would yield gases containing 10 per cent hydrogen. Reduction of the magma temperature at 600C would produce a higher methane gas content. An annual production rate of 26 billion cu ft of hydrogen is predicted for large basaltic magma chambers with a 12 per cent ferrous iron content at 1,200C. Magma sources are thought to be located approximately 2-3 km below the ocean floor, within the range of current drilling technology. Steam, a by-product of the process, can be used in electrical power generation.
Waste treatment processes	R. Dyment, "Truck-tankers clean septic tanks in rural areas", *Water and Sewage Works*, vol. 125, No. 1, January 1978.	A 4,000 gallon sewage tanker truck is used by Rural Sanitation Service, Inc, of Clarence, New York, to clean septic and holding tanks in unsewered areas. Sewage is removed from the septic tanks by a rotary stainless steel Vane pump with continuous vaccum pressure. The rotor is equipped with sliding vanes mounted along the rotor's circumference. When the vanes are pushed outward by centrifugal force, the rotor casing is divided

Subject	*Source*	*Description*
		into separate compartments. The volumetric capacity of these compression compartments is maximized during rotation, causing air to be drawn in and compressed. Air is cleaned in the compressor by an oil filter and is prevented from flowing out through the air receiver by a non-return valve. Sewage pumped from the septic tanks to the tanker truck is removed either to a municipal treatment facility, a sanitary landfill, or to a farm where it is used in land applications. The sewage sludge is buried in trenches 8-10 inches below the field surface in batches of 1500 gallons for land fertilization.
Waste treatment processes	"Mini Sewage Works", *Water Services*, vol. 81, No. 982, December 1977, p. 760.	A municipal sewage treatment unit, developed by Simon-Hartley of Stoke-on-Trent, England, provides extended aeration for small volumes of municipal effluent. The treatment unit is designed for simple operation in municipal facilities, where volumes of sludge produced are limited, or in warm climates where sludge is used for irrigation. The compact unit treats fluctuating flows in communities where sewage output may increase several fold at certain periods of the day. The Capitox treatment unit uses initial coarse screening of influent, followed by the mixing of the raw sewage with recirculated sludge before aeration. A Simcar aerator is employed; a weir box passes the liquid effluent into the settling basin containing an inlet stilling box and a weir. Solids are screened before leaving the aeration tank; sludge is removed from the settling tank and returned to the begining of the treatment cycle for mixing with the influent. Tanks are constructed of either steel or concrete from a variety of components, dependent upon the specific application.
Waste treatment processes	M.K. Gupta, "Development of a mobile treatment system for handling spilled hazardous materials", National Technical Information Service, Springfield, VA 22161 (PB-256 707, 1976).	Laboratory and engineering studies conducted to determine the design of a mobile hazardous material spills treatment trailer are documented. The trailer and its main components (pumps, portable reaction and storage tanks, mixed media filters, activated carbon columns, etc.) are described; a summary of spill response capabilities is presented. The trailer is a mobile self-contained, modular filtration/carbon adsorption unit designed for one-site treatment of spilled hazardous water-soluble organics. Nine materials, selected on the basis of the priority ranking system developed by the Environmental Protection Agency (EPA), were evaluated: acetone cyanohydrin, acrylonitrile, ammonia, chlorinated hydrocarbons, chlorine, methanol, phenol, tetraethyllead (TEL), and tetramethyllead (TML). Several others were evaluated for treatment feasibility by reverse osmosis. The unit treatment processes of chemical reaction, flocculation, sedimentation, granular media filtration, and activated carbon adsorption formed the most suitable and versatile system for on-site removal and treatment of hazardous materials. A 126 l/sec (200 gpm) mobile system was constructed based on the design data outlined. Reverse osmosis can be utilized on a selective basis for the treatment of water soluble inorganics but is unsuitable for many materials because of their

Subject	*Source*	*Description*
		low water solubility and effect on membranes. Optimum processes (including activated carbon adsorption, chlorination, coagulation, filtration, and physical-chemical methods) are outlined for treatment of acetone cyanohydrin, acrylonitrile, chlorine, phenol, ammonia, pesticides, herbicides, methanol, TEL and TML.
Waste treatment processes	M.D. Kavanagh, "Water Reclamation and Recycling", *Chartered Municipal Engineer*, vol. 105, No. 1, pp. 7-14, January 1978.	Water recycling and reclamation practices are reviewed for municipal and industrial wastes and water supplies. A study of the River Exe in England revealed that the river's water was reused three times through removal for municipal water supplies and discharge from treatment plants. A total of 92,901 cu m was removed and 70,038 cu m discharged daily as indicated by licensed users of the River Exe. Fifty sewage treatment plants are located within the River Exe basin. Research and methods for the recycling of sewage for potable water supplies are discussed. Industrial plants have the option of treating their own wastes or discharging them to municipal or regional waste treatment plants. The latter alternative involves a surcharge tax for discharge or a contribution to treatment plant construction and operation, eliminating discharge costs. In-plant industrial treatment processes were examined at a cement company which recovers materials from its concrete mixer using recycled water at a significant savings. The reuse of municipal sewage for industrial cooling was cited for electrical powerplants, steel manufactures, gas production and food processing industries.
Waste treatment processes	"Waste treatment plant", Australian patent 488,148, *Australian Official Journal of Patents, Trade Marks, and Designs*, vol. 47, No. 43, p. 3920, November 1977.	A waste water treatment tank that utilizes an aeration process and a settling basin has been patented. The tank is divided into two parts by an interior, centrally-located baffle. One side of the tank contains an aeration unit which aerates the waste water and maintains a continuous state of turbulence. The waste water passes into the aeration chamber of the tank through an inlet. After aeration, it is transferred by the interior baffle into the adjacent settling chamber containing an outlet. The waste water undergoes settling in this chamber; scum is recovered from the waste and recirculated to the aeration chamber via a recirculation device.
Waste treatment processes	"Hong Kong's largest sewage works", *Water and Waste Treatment*, vol. 21, No. 1, p. 6-7, January 1978.	A municipal sewage treatment plant currently under construction for Sha Tin near Hong Kong will have a daily capacity of 102,000 cu m of raw sewage when completed in 1980. The treatment facility, which will employ two physical treatment stages and one biological stage, will contain primary sedimentation tanks, aeration tanks, final settling tanks, sludge digestion and storage tanks, as well as a laboratory, an administration building, and a power generation building. The treatment facility will remove 92 per cent of the pollutants in the sewage effluent before discharge into a landlocked harbour; provisions have been made for a tertiary treatment facility to protect the quality of the receiving habour if necessary. The plant will receive a maximum flow of 3.6 cu m/second; biological treatment for

Subject	*Source*	*Description*
		nitrogen removal from the effluent will reduce the possibility of red tides in the harbour. The Sha Tin treatment facility, when fully developed, will be capable of treating sewage effluent from a population of 500,000.
Water quality control	H.F. Bormann and G.E. Likens, "The fresh air - clean water exchange", *Natural History*, vol. 86, No. 9, November 1977.	Studies of small New Hampshire forest watersheds (30-100 acres) show they provide very important pollutant-removal benefits to humans, all powered by solar energy; but forest vegetation and soils eventually come into equilibrium with pollution loads, lose their storage function, and the ecosystem may be damaged. Forests modify streamflow and erosion, filter air and water, release sediment-free water to underground and surface-water supplies, and moderate temperature and humidity. Large quantities of nutrients move about freely between vegetation and soil, but little is lost in drainage water, and such losses are made up by rock weathering. A forest regulates the chemical quality of water percolating through it into streams or to ground water. Nitrate present in increasing amounts in rainfall is mostly being held within the forest ecosystem. Because of increasing use of fossil fuels, rainfall in the north-eastern United States is now largely a mixture of water and sulfuric and nitric acids. The forest ecosystem removes much of this acid from rain water, so that stream water draining from the watersheds is 30 times less acid than rain water. Natural soils remove heavy metals, some radioactive isotopes, and pesticides. Soil and forest vegetation also remove many particulate and gaseous pollutants from the air: vegetation is especially efficient in removing sulfur from the air, and forest soil absorbs large amounts of carbon monoxide.
Water quality control	H.Z. Evan, "Environmental management in a mediterranean port city: Haifa", *Ambio*, vol 6, No. 6, pp. 346-349, 1977.	A two-year experimental environmental management project conducted in Haifa, Israel, was co-sponsored by the Environmental Protection Service, the city of Haifa and the United Nations Environment Programme. A municipal agency was established to monotor air quality, river and beach pollution, and solid waste disposal. The agency was also responsible for establishing industrial co-operation, urban planning studies, and information services to public and legislativw bodies. Air quality management has focused on monitoring stations, emission inventory, microclimatic studies, and industrial stack emissions, especially during inversions. An autonomous River Authority has been proposed to prevent pollution of the Kishon River with agricultural and industrial wastes. A 1,000 ton/day recycling facility has been proposed as a solution to the diminishing sanitary landfill areas. Reduction of coastal pollution by tanker oil and bilge water has been attempted by the provision of cleaning facilities and increased surveillance. Urban planning has concentrated on limiting population densities and separating residential and industrial areas. Legislation has been introduced for the dissemination of information to the public and for administering guidelines.

Subject	*Source*	*Description*
Water quality control	A.S. Lagrange, "The Barcelona convention and its protocols", *Ambio*, vol. 6, No. 6, 1977.	The 1976 Barcelona Convention, in which 16 Mediterranean coastal countries participated, resulted in international agreements for controlling pollution in the Mediterranean Sea. Fifteen countries have signed agreements establishing the Convention as a framework for protection of the ocean from pollution, control of the dumping of pollutants by ships and aircraft, and regulation of pollution in the Mediterranean Sea by oil spills. Three categories of wastes were identified within the protocol regulating pollution by ships and aircraft. One category lists the various substances which are totally probihited; the second details those pollutants which require a special permit from the appropriate authority before dumping; and the third category covers the general range of all other wastes and matter for which a general dumping permit is necessary. A list of totally prohibited pollutants, including acid and alkaline compounds, is currently under consideration for adoption. The second pollution abatement protocol adopted by the Convention establishes a regional data collection centre and mandates international co-operation in controlling, monitoring, recovering, and identifying pollution caused by an emergency or accidental situation. No agreement could be reached among the participating countries on the control of land-based pollution sources.
Water quality control	"Quality criteria for water, July 1976", Environmental Protection Agency, Washington, D.C., Office of Water and Hazardous Materials, 1977.	This volume addresses the effects of those basic water constituents and pollutants that are considered most significant in the aquatic environment in the context of present knowledge and experience. The format for criteria presentation has been altered substantially from the previous volumes. It is believed that the alphabetical arrangement of the water quality constituents and the form in which the information is arranged will be of considerable help to the reader in using this volume. For each basic water constitutent or pollutant there is a recommended criterion, an introduction, a rationale supporting the recommended criterion, and a list of the references cited in the development of the recommendation. The volume is to recommend criteria levels for a water quality that will provide the protection and propagation of fish and other aquatic life and for recreation in and on the water in accord with the 1983 goals of P.L. 92-500. Criteria also are presented for the domestic water supply use. Generally, these uses require water of the highest achievable quality, and water quality that supports these uses will also be suitable for agricultural and industrial uses.
Water quality control	R.E. Franz, "Public behaviour and attitudes in response to reported hazardous drinking water. A feasibility study," National Technical Information Service, Springfield, Va 22161 (No. PB-257 981, September 1976).	When it was learned that asbestiform fibres were present in the drinking water of Duluth, Minnesota, concern was manifested immediately and the Army Corps of Engineers provided filtred water for anyone wanting it. However, it was soon discovered that asbestiform contamination was not unique to Duluth and it was determined to test public attitudes on the use of filtred water where drinking water was reported hazardous. This report of the feasibility study presents a survey

Subject	Source	Description
		design to be used in this determination and includes suggestions for sampling techniques and measurement considerations. The recommended questionnaire was pre-tested in Duluth and a pilot study was undertaken there with a total of 50 completed questionnaires resulting from the pilot study: the results indicate that such a feasibility study can be successfully pursued.
Water treatment and quality alteration	L.V. Gutierrez, Jr., "Water supply feasibility studies in Philippines", *Journal of the Urban Planning and Development Division*, vol. 104, No. UPI, Proceedings of the American Society of Civil Engineers, pp. 59-71, May 1978.	Field tests show that most water distribution systems have old and inadequately sized pipes with considerably reduced capacities, resulting in low pressures and marginal fire-fighting capabilities. Water sources, both surface and ground, are generally available, but water-handling facilities must be properly planned and constructed to convey the water to the demand centres. Water demand will increase exponentially as population grows and standard of living and opportunity increases. Quantifiable economic benefits exceed the known costs of the water supply construction stages, which are financially viable if water rates are set on the basis of the consumers' ability to pay. As a result of these feasibility studies, water supply projects are now being provided much needed foreign exchange by international loaning agencies.
Watershed protection	H.E. Dregne, "Desertification in the United States", *Nature and Resources*, vol. 13, No. 2, pp. 10-13, April-June 1977.	Desertification is a process of land degradation that is the result of an often complex interaction among people, plants, animals, land and climate. Three instances of widespread desertification in the United States during the past one hundred years are described: (1) overgrazing in the desert grasslands, (2) salinization of irrigated lands, and (3) wind erosion in the Great Plains during the protracted drought of the 1940s. The overgrazing resulted in severe erosion. Salinization and waterlogging began to affect large areas shortly after a rapid expansion of irrigation began in the arid west at the end of the nineteenth century. The problems of Colorado River project storage and increasing salinization are discussed. The lack of resilience in arid lands makes it essential that signs of desertification be recognized before degradation has assumed major proportions.
Watershed protection	W.C. Moldenhauer, "Water erosion", *Agricultureal Research Service Publications*, No. 57, pp. 47-51, October 1977.	A brief review of past and present research on soil erosion control includes a discussion of research needs and approaches, expected benefits, and the potential for a predictive model. Some four billion tons of sediment annually enter surface waters in the United States according to a 1967 estimate, compared with three billion tons 30 years earlier. The first soil erosion research plots were established in 1917. Beginning in 1928, research stations were created to monitor precipitation, runoff, and soil loss; most have now been discontinued. In recent years most research has been conducted with rain simulators, and deals with erosion control aspects of surface residue tillage. Methods for prediction of soil and water loss from cropping systems have been successfully developed, including the

Subject	*Source*	*Description*
		Universal Soil-Loss Equation. Seeded backslope terrace experiments were initiated in Iowa in 1964-1965. Surface residue tillage, the best method for combined wind and water erosion control, nevertheless gives only limited protection. On long or steep slopes runoff may undercut much or carry it awav, with resulting high soil erosion. Research is needed on tillage-mulch-soil interrelationships to design a tilled zone for minimum runoff. Erosion control could eliminate pollution of surface waters by phosphorus-laden sediment.

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